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PSDDA Reports

Puget Sound Dredged Disposal Analysis

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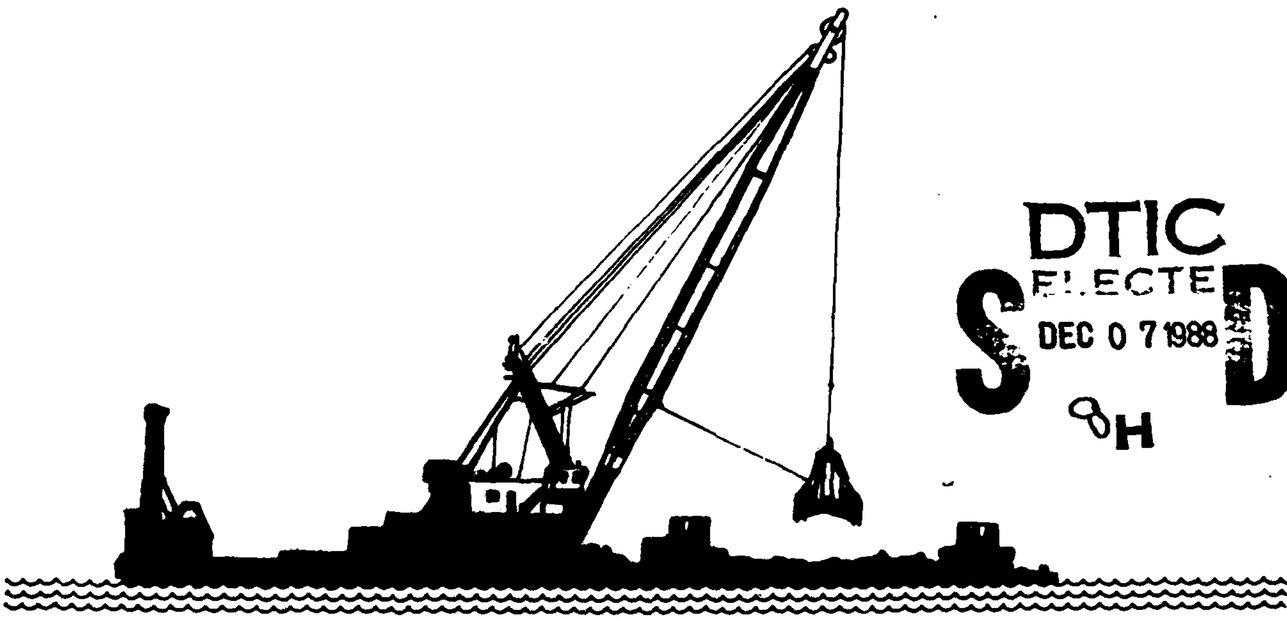
Washington State Dept. of Natural Resources

DISPOSAL SITE SELECTION TECHNICAL APPENDIX - PHASE I (CENTRAL PUGET SOUND)



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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
US Army Corps of Engineers, Seattle District

6c. ADDRESS *(City, State, and ZIP Code)*

7b. ADDRESS *(City, State, and ZIP Code)*
PO Box C-3755
Seattle, WA 98124-2255

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
Unconfined open-water disposal sites for dredged material in Central Puget Sound, Phase I. Vol. 3

12. PERSONAL AUTHOR(S)

13a. TYPE OF REPORT
Final EIS

13b. TIME COVERED
FROM ________ TO ______

14. DATE OF REPORT *(Year, Month, Day)*
June 1988

15. PAGE COUNT
5 volumes, various paging

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Dredging
Open-water disposal
Puget Sound

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This final environmental impact statement evaluates alternatives considered in identifying preferred sites for disposal of dredged material in Central Puget Sound. Three public multiuser disposal sites (Commencement Bay, Elliott Bay, and Port Gardner) are identified for use based on a site selection process which considered several alternative sites. Alternative biological effects conditions for site management have been considered and a site condition identified for purposes of dredged material management at the Phase I sites.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
unclass.

22a. NAME OF RESPONSIBLE INDIVIDUAL
Pat J. Perry

22b. TELEPHONE *(Include Area Code)*
(206)764-3728

22c. OFFICE SYMBOL
CENPS-IM-CA-LB

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

DISPOSAL SITE SELECTION TECHNICAL APPENDIX

Unconfined Open-Water Disposal Sites for Dredged Material in Central Puget Sound

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Puget Sound Dredged Disposal Analysis (PSDDA)

ORGANIZATIONAL PREFACE

This document is a technical appendix to the Puget Sound Dredged Disposal Analysis (PSDDA) Management Plan Report and Final Environmental Impact Statement for the Phase I study area (central Puget Sound). The appendix was prepared by the Disposal Site Work Group (DSWG), assigned the responsibility for identifying potential unconfined, open-water dredged material disposal sites.

Part 1 of the Disposal Site Selection Technical Appendix contains introductory and conceptual information for the remaining parts of the document. Part II contains the detailed presentation of the site selection process employed by DSWG. Keywords:

Dredging; Dredged materials disposal; Puget Sound; Open water disposal; Biological effects. (edc)

ACKNOWLEDGEMENTS

The Disposal Site Work Group acknowledges the assistance of Evans-Hamilton, Inc. in the preparation of this technical appendix. Principal contributors were Curtis C. Ebbesmeyer and Clayton B. Wilson.

EXECUTIVE SUMMARY

This document is a technical appendix to both the Management Plan Report (MPR) and the Final Environmental Impact Statement (EIS) for the Puget Sound Dredged Disposal Analysis (PSDDA) study. The technical appendix was produced by the Disposal Site Work Group (DSWG), which included the U.S. Army Corps of Engineers as lead agency, supported by the U.S. Environmental Protection Agency (EPA), and the Washington Departments of Ecology and Natural Resources.

The technical appendix summarizes results for the Phase I area of PSDDA, which includes the central portion of Puget Sound from Everett to Tacoma. DSWG's task for Phase I was to identify suitable unconfined open-water disposal sites. This technical appendix summarizes the process by which DSWG carried out its task.

Preferred unconfined, open-water disposal sites have been identified in the Everett, Seattle, and Tacoma urban embayments of Port Gardner, Elliott Bay, and Commencement Bay, respectively. The sites, while varying in size primarily due to bathymetry, average about 350 acres in potential bottom impact area. Each site includes a 900-foot radius, 58-acre surface disposal zone within which all dredged material must be released.

The preferred disposal sites are all located to avoid areas with important biological resources and human use activities. The center of the Port Gardner preferred disposal zone is located about 2-1/4 miles southeast of Gedney Island in approximately 420 feet of water. In Elliott Bay, the center of the preferred disposal zone is located about 3/4 of a mile north of Harbor Island in water 265 feet deep. The center of the Commencement Bay preferred disposal zone is located approximately 1 mile west of Browns Point in water about 530 feet deep.

The site selection process used by PSDDA utilized existing information in combination with field studies to identify preferred and alternative disposal sites. Steps of the site selection process were as follows:

(1) Define general siting philosophy. This step addresses disposal philosophy (i.e., dispersive versus nondispersive), general siting locations (i.e., ocean, strait, or sound), and number of disposal sites.

(2) Identify selection factors to delineate Zones of Siting Feasibility (ZSFs). This step uses exising information on biological resources and human use activities to identify general areas where disposal sites might be appropriately located.

(3) Conduct field studies on the ZSFs. Field and model studies are conducted to fill key data gaps and gather information on the physical and biological conditions of the ZSFs. Since these studies were conducted to check the general condition of the ZSFs, they are referred to as "checking studies."

(4) Identify preliminary sites within each ZSF. Information from the ZSF studies is used to identify preliminary locations for disposal sites within the ZSFs.

(5) Conduct field studies on the sites. Field and model studies are conducted to obtain needed physical and biological information for the preliminary sites. These studies are referred to as "site-specific studies."

(6) Identify preferred sites. Information from the site-specific studies is used to identify preferred and alternative sites.

Existing DNR disposal sites were considered in the disposal site selection process if they met certain site selection factors. All cooperating agencies in PSDDA agreed early on that no special a priori consideration would be given to the existing sites because of human use conflicts and environmental concerns with past dredging and disposal protocols. An objective site selection process was used to minimize environmental and human usage conflicts as much as possible, and existing sites adequately meeting the site selection factors and constraints were given equal consideration with other potential sites.

The key steps in the site selection process were as follows. First, Zones of Siting Feasibility (ZSFs) were found by overlaying many maps of human and biological resources. A numerical dredged material disposal model was also used to determine the size of the disposal sites in various water depths and water speeds. The map overlays and model results resulted in ZSFs large enough to embrace potential disposal sites in the vicinity of major dredging activity near Everett, Seattle, and Tacoma.

Second, more detailed maps were constructed of the ZSFs describing three basic characteristics: 1) current strength; 2) sediment character; and 3) biological resources. From maps of current strength and results from earlier dredging activities it was determined that dredge materials would be resuspended at current speeds faster than half a knot. Because a non-dispersive philosophy was adopted, areas were sought where dredged material would not be significantly transported or where current speeds were less than half a knot. These areas also coincided with characteristics indicating that these areas were depositional, i.e., where sediments tended to naturally accumulate. Fortunately these low-current, depositional areas also contained relatively low populations of crab, shrimp, and bottomfish when compared to commercial and recreational areas of Puget Sound.

The proposed disposal sites were placed in these low current (peak 1 percent current velocities less than 25 cm/s), depositional, and minimally populated areas within the ZSFs. Although the inner Elliott Bay site had some shrimp densities that were high compared to other ZSFs, when compared to commercial areas it is a relatively low shrimp area. A commercial fishery for shrimp would also be unable to operate because of the high commercial shipping activity. The capacity of the preferred disposal sites is estimated to be several times the volume of dredged material disposal projected through the year 2000.

PUGET SOUND DREDGED MATERIAL DISPOSAL ANALYSIS

DISPOSAL SITE SELECTION TECHNICAL APPENDIX

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PART I. INTRODUCTION

1. STUDY GOALS, DESCRIPTION, AND ORGANIZATION

This technical appendix addresses the identification of disposal sites for unconfined, open-water disposal of dredged material in central Puget Sound (Fig. I.1-1) as specified pursuant to the Clean Water Act and related authorities. The site selection process for the Phase I area (central Puget Sound) of the Puget Sound Dredged Disposal Analysis (PSDDA) is presented. A review and synthesis of studies conducted, information gathered, and analysis performed during the disposal site selection process are provided.

Since the 1970's relatively high concentrations of chemical contaminants have been found in some sediments of a number of bays in Puget Sound. These contaminants have also been identified in fish, shellfish, and other organisms. While research is continuing about the ways in which exposure to contaminated sediments affects marine life or human health, recent field studies have noted some adverse biological effects in areas of high sediment contamination.

Dredging is necessary to keep shipping channels and harbors open, to construct new ports, and sometimes to clean up contaminated material. Consequently, dredging in Puget Sound is an ongoing necessity and has been commonplace for many years.

Five basic disposal options are available. These include unconfined open-water, unconfined nearshore/upland, confined aquatic disposal, confined nearshore, and confined upland areas. The three confined options result from the need to address sediment contamination levels that are unacceptable for unconfined or conventional disposal. See the Evaluation Procedures Technical Appendix (EPTA) for a detailed discussion of disposal options. Open-water sites are located offshore in deep-water areas. Unconfined open-water disposal occurs through free fall of released material to the bottom with no subsequent handling. Confined aquatic disposal involves follow-up capping with material suitable for unconfined open-water disposal. Nearshore disposal sites are typically diked aquatic areas, but the final surface of the site is usually above the waterline. Upland disposal sites are areas created on land entirely above the waterline, and are often diked. PSDDA is addressing unconfined open-water disposal in detail (siting, dredged material evaluation procedures, and site management), but is addressing all other disposal options in a generic manner (mostly evaluation procedures, no sites, little management/permitting).

Cost effective evaluation, disposal, and management of dredged material is essential to the economic interests of the Puget Sound region which serves as a major deep water port for

the nation. More than 200 small boat harbors meet the needs of commercial fishing vessels and pleasure craft in the Puget Sound region. Periodic dredging is necessary in most of these harbors as well as in the major ports. For uncontaminated dredged material, disposal at unconfined, open-water sites has been the least costly alternative. As upland and intertidal areas become more difficult to secure, the demand for this type of disposal will increase.

1.1 Puget Sound Dredged Disposal Analysis

The Puget Sound Dredged Disposal Analysis (PSDDA) is an interagency study which involves the U.S. Army Corps of Engineers (Corps) as lead agency, supported by the U.S. Environmental Protection Agency (EPA) and the Washington Departments of Natural Resources (DNR) and Ecology (Ecology). The goal of PSDDA is to provide the basis for publicly acceptable guidelines governing environmentally safe unconfined, open-water disposal of dredged material, and to provide Puget Sound-wide consistency and predictability. The objectives of PSDDA are as follows:

- o Identify acceptable unconfined, open-water disposal sites.
- o Define acceptable evaluation procedures for dredged material to be discharged at those sites.
- o Develop site use management plans.

Three work groups have been formed to address these objectives with each group staffed by the four agencies conducting PSDDA: Army Corps of Engineers (Corps); U.S. Environmental Protection Agency (EPA); Washington State Departments of Ecology (Ecology); and Natural Resources (DNR) serving on each work group. Many others including representatives from Puget Sound ports, environmental groups, Indian tribes, dredging industry, local governments, and other state and Federal agencies are also participating in work group activities. The work groups under the general guidance of the PSDDA Study Director, have conducted a number of technical studies. Each work group produced a technical appendix which summarizes these studies. These work groups include:

- o Disposal Site Work Group (DSWG)
- o Evaluation Procedures Work Group (EPWG)
- o Management Plan Work Group (MPWG)

DSWG was assigned the responsibility for selecting unconfined, open-water disposal sites in central Puget Sound. DSWG produced the Disposal Site Selection Technical Appendix (DSSTA) which addresses the identification of disposal sites for unconfined, open-water disposal of dredged material in central Puget Sound, as specified pursuant to the Clean Water Act and related authorities.

EPWG was assigned the responsibility for developing a decision-making framework and technical specifications for assessing the quality of dredged material and delineating materials which are suitable for unconfined, open-water disposal. EPWG produced the Evaluation Procedures Technical Appendix (EPTA) which addresses the development of evaluation procedures (testing and disposal guidelines) for determining when dredged material is suitable for unconfined, open-water disposal pursuant to the Clean Water Act.

MPWG was assigned the responsibility for developing the management plan for each of the unconfined, open-water disposal sites. MPWG produced the Management Plans Technical Appendix (MPTA) which addresses the management of sites to be used for unconfined, open-water disposal of dredged material in central Puget Sound, pursuant to implementation of the Clean Water Act and related authorities.

In addition to PSDDA there are other ongoing programs in Puget Sound. In particular, the work conducted by PSDDA required detailed coordination with the Puget Sound Estuary Program (PSEP) and the Puget Sound Water Quality Authority (PSWQA). In fact, PSDDA was essentially called for originally in the first scope (initiative) of PSEP, and is considered to be a separate component of the overall estuary program. The charter of the PSWQA also includes dredging issues. The Authority's December 1986 Comprehensive plan is being developed in close coordination with PSDDA.

The work of PSDDA is divided into two phases that differ geographically and temporarily. Phase I of the study began in April, 1985 and covers a smaller geographic area than Phase II (Fig. I.1-1). The Phase I study area includes Puget Sound from Everett south to Tacoma, and Port Susan north of Everett. The focus of this Technical Appendix is Phase I of the PSDDA study, but public scoping meetings have been held by PSDDA in the Phase II communities of Olympia, Port Townsend, and Bellingham. These meetings were held to ensure that in the Phase II area the public would have an opportunity to influence the Phase I process.

Phase II of the PSDDA study overlaps the Phase I area and includes Puget Sound northward to the Canadian border and southern Puget Sound. The Phase II study began in 1986 and will end one year later than Phase I.

The regulatory context of the PSDDA study is Section 404 of the Clean Water Act of 1977 (Public Law 92-500), which

establishes a Federal permit system for the disposal of dredge and fill material, and Section 401, which requires a water quality certification from the state prior to issuance of a Federal permit. The Coastal Zone Management Act (Public Law 92-583) requires that Federal and non-Federal projects in a particular state be consistent to the maximum extent practicable with the state's coastal zone management program. The appeal process differs between Federal and non-Federal projects not in compliance. In addition, Section 10 of the 1899 Rivers and Harbors Act also applies to disposal activities in navigable waters. A more detailed description of the requirements relevant to disposal of dredged materials is presented in Part II.1 of the Evaluation Procedures Technical Appendix.

1.2 Disposal Site Work Group (DSWG)

The goal of the Disposal Site Work Group was to develop and implement site selection criteria for choosing unconfined, open-water disposal sites that are environmentally acceptable, practicable, and economically feasible. The site selection process has identified sites that are acceptable for dredged material in full compliance with 404(b)(1) guidelines. The DSWG's charter also includes developing guidelines for site use and establishing parameters for the environmental baseline and subsequent monitoring studies.

1.3 Management of the Disposal Site Work Group

1.3.1 Participants and Coordination of Work--

Four agencies are the principal participants in DSWG. The lead and chair agency is the U.S. Army Corps of Engineers (Corps). The U.S. Environmental Protection Agency (EPA) and the Washington State Departments of Natural Resources (DNR) and Ecology (Ecology) are supporting agencies. Representatives of these agencies meet as necessary to coordinate the work. In addition to the four primary agencies; Indian tribes, port, city, county, other state and Federal agencies, and other interests were also involved in the activies of the DSWG (Table I.1-1).

For all meetings (Table I.1-2), minutes were recorded that summarized the conclusions of the work group discussion. Meetings were frequent enough to enable many discussions of the relevant issues. The ultimate resolution of the issues appears in this technical appendix.

Another function of the DSWG meetings was general monitoring of the work as it proceeded. This monitoring included contract oversight and review of technical documents submitted by the various agencies and contractors.

1.3.2 Public Involvement--

The public was also involved in the DSWG decision-making process through a series of meetings held at a number of locations. These meetings were publicized through news media coverage, informational brochures, newsletters, and by encouraging involvement of various organizations.

TABLE I.1-1 PSDDA-DSWG PARTICIPATING AGENCIES & ORGANIZATIONS.

- State of Washington

Department of Fisheries (WDF)
Department of Game (WDG)
Department of Social and Health Services (DSHS)
Puget Sound Water Quality Authority (PSWQA)
University of Washington School of Fisheries

- Federal

National Oceanic and Atmospheric Administration (NOAA)
U.S. Fish and Wildlife Service (USFWS)
U.S. Coast Guard (USCG)

- Local Governments/Agencies/Port Districts

Mason County
Thurston County
Island County
Jefferson County
Kitsap County
Snohomish County
King County
Pierce County
City of Everett
City of Seattle
City of Tacoma
Municipality of Metropolitan Seattle (METRO)
Puget Sound Council of Governments (PSCOG)
Port of Bellingham
Port of Everett
Port of Seattle
Port of Port Townsend
Port of Tacoma
Port of Anacortes
Port of Edmonds
Port of Olympia
Port of Port Angeles
Port of Skagit County

- <u>Indian Tribes</u>

  Muckelshoot
  Puyallup
  Tulalip
  Suquamish

- <u>Environmental Groups/Organizations</u>

  Puget Sound Alliance
  League of Women Voters
  Greenpeace
  Washington Environmental Council
  Friends of the Earth

- <u>Private Citizen</u>

  Bonnie Orme

- <u>Other</u>

  Tetra Tech, Inc.
  Cooper and Associates (Cooper)
  Evans-Hamilton, Inc. (EHI)
  Shapiro and Associates (Shapiro)
  Envirosphere, a division of Ebasco, Inc.
  Institute of Marine Studies, University of Washington
  Washington Association of General Contractors
  Washington Association of Cities
  Washington Public Port Association
  Battelle Memorial Institute (Battelle)
  Magnolia Bluff Homeowners Association
  Northwest Indian Fisheries Commission

TABLE I.1-2 MEETING DATES OF THE DISPOSAL SITE WORKING GROUP (DSWG).

Meeting No.	Date
1	4 April 1985
2	9 April 1985
3	18 April 1985
4	30 April 1985
5	7 May 1985
6	28 May 1985
7	4 June 1985
8	18 June 1985
9	2 July 1985
10	16 July 1985
11	31 July 1985
12	15 Aug 1985
13	10 Sept 1985
14	26 Sept 1985
15	15 Oct 1985
16	12 Nov 1985
17	3 Dec 1985
18	18 & 19 Dec 1985
19	14 Jan 1986
20	18 Feb 1986
21	18 Mar 1986
22	22 Apr 1986
23	3 June 1986
24	17 July 1986
25	23 July 1986
26	28 July 1986
27	26 Aug 1986
28	15 Sept 1986
29	2 Oct 1986
30	22 Jan 1987

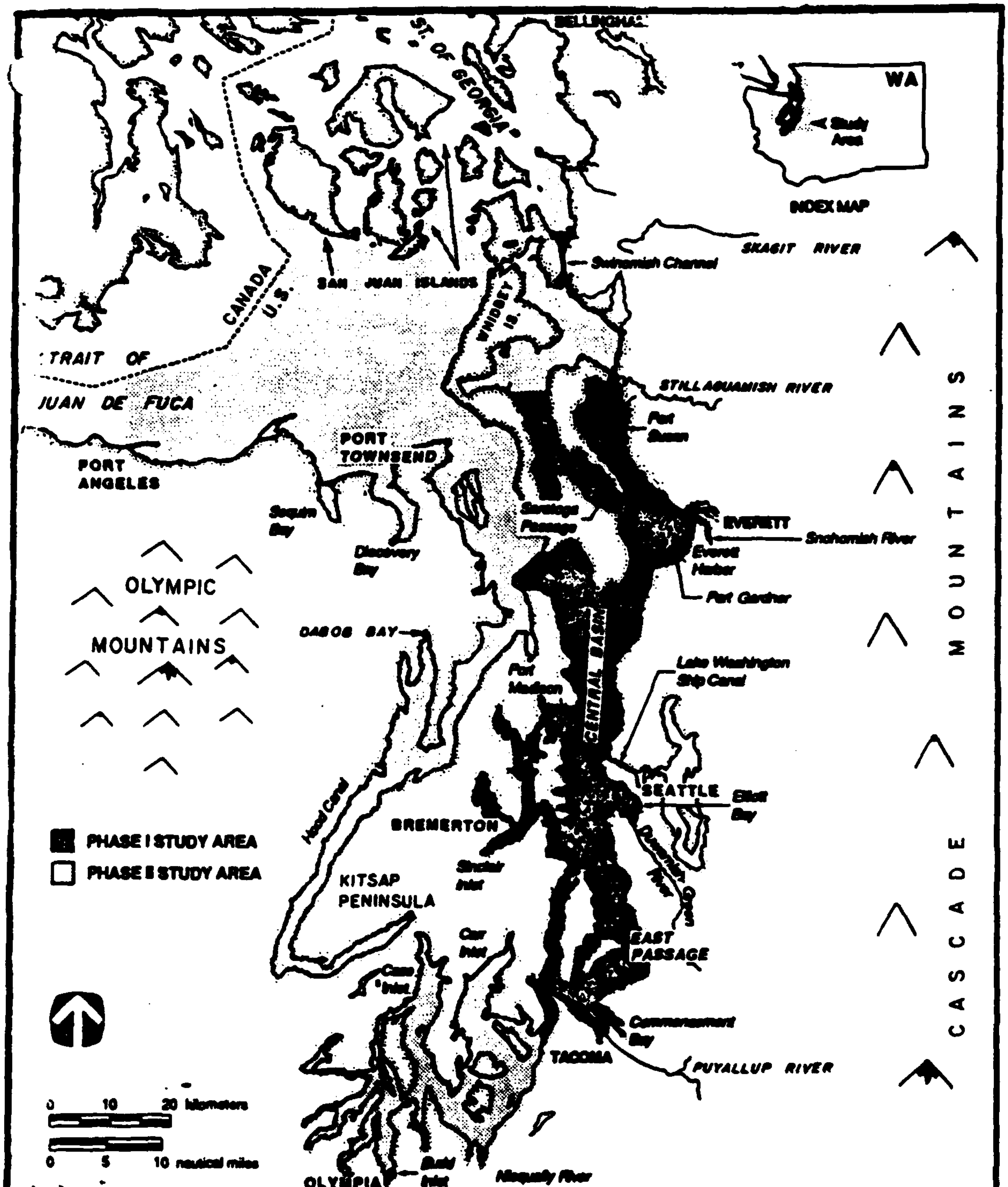


Figure I. 1-1 PSDDA Study Area. (Source: Tetra Tech)

2. DISPOSAL SITE SELECTION BACKGROUND

2.1 Definition of Dredged Material

The scope of the PSDDA study is limited to the disposal of dredged material. Upland construction material, waste, and debris are not considered. In open water areas, dredged material is defined as sediment and bottom materials that are removed during dredging operations (e.g., clay, silt, sand, and rocks). The definition of dredged material is more complex when dredging operations occur along the shoreline. The reader should consult the Evaluation Procedures Technical Appendix for a discussion of dredging along the shoreline. This discussion includes material classed as excavation material which is not considered for disposal in marine waters. Historically in Puget Sound, some of this excavation material has been informally considered as dredged material, and will continue to be included as dredged material only if there would be an ecological benefit at the disposal site.

2.2 Existing Unconfined, Open Water Disposal Sites in the Phase I Area

Currently, there are deep water disposal sites in Port Gardner, Elliott Bay, and Commencement Bay. The chemical characteristics of these sites are summarized in Appendix C of the EIS. Studies of biological characteristics at existing sites are summarized in Exhibit A. Each of these sites either overlaps, or is very near one of the disposal sites evaluated as part of PSDDA (see Figure I.2-1 and Figs. II.3-2 through II.3-5). The procedures utilized to select these existing sites are discussed in this section.

The DNR has used guidelines for selecting and managing the existing open-water disposal sites (WAC 332-30-166). These guidelines are fairly general and contain the following key points:

- o Open water sites shall be used almost exclusively for material obtained from marine or fresh waters.
- o The material must meet the approval of Federal and state agencies.
- o In selecting disposal areas, consideration must be given for the sites' natural characteristics, probable dispersal patterns, substrate type, proximity to dredge sites, and living resources (including aquaculture).
- o Special consideration must be given to discharges by pipeline.

- o The department may require investigations of biological and physical systems, and may perform subtidal surveys.

The existing open-water disposal sites were selected, reviewed, and operated by DNR in conjunction with the Inter-Agency Open-Water Disposal Committee. This committee consisted of representatives from the DNR, Corps, National Marine Fisheries Service, EPA, U.S. Fish and Wildlife Service, and Washington State Departments of Game, Fisheries, and Ecology. Site selection by the committee followed the guidelines described above. The establishment of open-water disposal sites is subject to DNR obtaining a shoreline master use permit from the city or county having jurisdiction over the area.

Pursuant to the requirements of the Shorelines Management Act (SMA) of 1971 [Revised Code of Washington 90.58], cities and counties with shorelines on Puget Sound have developed Shoreline Master Programs (SMPs) and corresponding land use permitting processes, including regulation of uses on state-owned submerged lands. Very general guidelines have been established for open-water disposal sites [WAC 173-16-060(16)].

Land use permits issued by counties and cities fall into one of the following categories: Substantial Development Permit; Conditional Use Permit; or Variance Use Permit. Conditional Use and Variance Use permits require approval by the Washington Department of Ecology.

Shoreline Master Programs generally divide the shoreline area into segments of different environmental classifications in which permissible and prohibited land use activities are defined (e.g., Urban Residential, Conservancy, etc.). In addition to the land use permit requirements of the SMA, DNR must also fulfill the requirements of the State Environmental Policy Act (SEPA) when applying for a site permit for open-water disposal. The Environmental Impact Statement (EIS) requirements for SEPA are analogous to those of the National Environmental Policy Act (NEPA).

In summary, the DNR's permit application requirements for an open-water disposal site are:

- o Shoreline Substantial Development Permit
- o Conditional Use Permit (where needed)
- o Environmental Checklist
- o Preparation of an EIS, if environmental impacts are expected to be significant.

2.3 Reevaluation of Unconfined, Open-Water Sites

As described above, the state guidelines are very general and while adequate in the past they may not be effective today for determining if a given disposal site is environmentally and publicly acceptable, given the increase in information available to make the decisions. No field studies were conducted to determine the existing sites' biological and/or physical characteristics. However, the best available published information and the best judgement of site selection committee members had been used to select sites. Existing site use became a concern because of recent conflicts in obtaining shoreline permits from several jurisdictions and because new information has become available, which allows more informed siting decisions.

Disposal decisions previously had been made on the basis of water quality criteria. Tests used in checking for impacts on water quality gave no indication of impacts on the benthos and other resources from contaminants in dredged material. No other standards were available to interpret this data.

In response to increasing concerns regarding potential environmental and human health impacts associated with open water disposal of contaminated dredged material, the EPA and Washington Department of Ecology at the request of the City of Seattle and DNR, formulated disposal criteria for the open-water disposal site in Elliott Bay (Fourmile Rock). These were interim sediment criteria intended for use only until regional guidelines were developed.

The Seattle Department of Construction and Land Use (DCLU) awarded a shoreline permit to the DNR for continued use of the Fourmile Rock open-water disposal site. The Notice of Decision for the permit includes special terms and conditions: an analysis of the decision in terms of technical background, and SEPA; and interim disposal guidelines developed by Washington Department of Ecology and the EPA (see EPTA for further discussion).

2.3.1 Need for Unconfined Open-Water Disposal Sites—

2.3.1.1 Dredging in the Phase I Area

Phase I of PSDDA focuses on dredging activities in the central area of Puget Sound, including maintenance navigation dredging and dredging for new port facilities. During 1970-1985 approximately seventeen million cubic yards were disposed in open water in the Phase I area. There are a number of Federal navigation projects in the Phase I area of Puget Sound that will require maintenance dredging by the Corps. It is expected that

the previous 15-year total volume will be exceeded in the next 15 years, based on information for currently planned projects.

All of these projects have used and expect to continue to use unconfined, open-water disposal. Most dredging activity is highly dependent on the availability of nearby disposal sites because of economic considerations. Alternative disposal sites are generally not available without considerable increases in maintenance costs (e.g., upland sites). Disposal at confined in-water or upland sites, while dependent on the specific project, is estimated to cost from three to ten times more per cubic yard than present open-water disposal. These cost differences affect the feasibility of many dredging projects. See EPTA for a full discussion of cost implications of PSDDA requirements on testing and monitoring, and for a discussion and analysis of environmental alternatives and cost implications to dredging and open-water disposal.

2.3.1.2 Dredging Areas

PSDDA has identified three major dredging areas centered around Everett, Seattle, and Tacoma. The largest quantities of dredged material is generated in these areas, with an additional area of significant dredging activity near Bremerton. The remainder of the dredging projects in central Puget Sound are sporadic in nature and generally consist of lesser quantities. Tables I.2-1 through I.2-3 identify major areas where dredged material is generated and indicate the total volumes of material deposited at the existing sites, volumes disposed in the period 1970-1985, and the 15 year projection of material to be dredged in each area.

Dredging activities in central Puget Sound have been reviewed and summarized in the Puget Sound Dredged Material Inventory System (Envirosphere, 1986). The Dredged Material Inventory was developed from Corps permit applications, EPA summary records, and other sources. Its purpose is to inventory the sources of dredged material and to characterize these dredged sediments with regard to location, volume, chemical composition, and known biological effects. The computerized database has been used to summarize historic and current dredging activities, and to project the volume and nature of sediments that may be dredged in the future.

2.3.1.3 Historic Dredging

Dredging operations in Puget Sound involve removal and disposal of large volumes of material. From the Dredged Material Inventory it has been estimated that a total of 16,850,000 cubic yards was dredged during the 15-year period from 1970 to 1985 (Table I.2-1). Approximately 40 percent of this total was

deposited at unconfined open-water disposal sites. Thus, an average of about 462,000 cubic yards of dredged sediment was deposited into Puget Sound each year during this period. The remainder of dredged material was deposited at nearshore or upland disposal sites. However, nearshore and upland sites have become scarce in recent years, and the use of unconfined, open-water disposal sites has increased. Whereas 24 percent of the material dredged by the Corps during the 1970's went to open-water sites, over 50 percent of the material dredged in the 1980's has been sent to open-water sites. Although Federal project use of open-water disposal sites varies considerably by site, Corps maintenance dredging and disposal activities have accounted for about 40 percent of the total volume of dredged material placed in Puget Sound through 1983 (PSDDA Phase I sites only; Table I.2-2).

2.3.1.4 Dredging Forecasts

The Dredged Material Inventory database has been used in conjunction with information on currently planned projects to project the total volume of sediment to be dredged in the Phase I area during the 15-year period from 1985 to 2000. A fifteen year planning horizon was used as it encompasses all known major navigation projects and is the maximum forecasting period that PSDDA felt could be established with reasonable certainty. The PSDDA disposal sites can accomodate dredged material well beyond the planning horizon as will be shown in Section II.10.3. The projected total volume to be dredged is 22,697,000 cubic yards, a volume 14 percent higher than the total dredged during the previous 15-year period. Of this total, most of the projected dredging activities will occur in four areas: Snohomish River; Lake Washington; Duwamish River; and Blair Waterway in Commencement Bay (Table I.2-3). Much of this dredging will be done by the Corps for navigation channel maintenance, and most of these projects have historically used open-water disposal sites. Permit applications also indicate that there will be a great demand for open-water disposal sites for other projects. Without the availability of the relatively less expensive open-water sites, some of these projects may not be economically feasible.

2.3.2 Concerns with Existing Sites--

Concerns were raised about using the existing disposal sites for a variety of reasons. The City of Seattle Department of Construction and Land Use required that an EIS be prepared to renew the shoreline permit at Fourmile Rock. There was also substantial public concern about this site being so close to a residential area and its proximity to a beach. In Port Gardner, concerns were raised about the lack of knowledge of biological resources and the possible impacts dredged material disposal might have on these resources.

2.3.3 Site Selection Philosophy--

Existing DNR disposal sites were considered in the disposal site selection process if they met certain site selection factors. All cooperating agencies in PSDDA agreed early on that no special a priori consideration would be given to the existing sites because of human use conflicts and environmental concerns with past dredging and disposal protocols. An objective site selection process was used to minimize environmental and human usage conflicts as much as possible; existing sites adequately meeting the site selection factors and constraints were given equal consideration with other potential sites.

2.3.4 Existing Information--

Earlier studies concerning the movement of dredged material mounds were made in Elliott Bay. One occurred in inner Elliott Bay under the dredged material research program (DMRP) and the other in the Fourmile Rock disposal site (Schell et al., 1976). These studies span a range of current speeds and provide the basis for the determination of the threshold speed for the movement of dredged material.

The DMRP site in inner Elliott Bay was monitored for approximately four years after disposal in 1976, and was selected for long-term monitoring under the Dredging Operations Technical Support (DOTS) Program (Dexter et al., 1984; Tatem, 1984). The studies were intended to determine if the disposal material remained at the disposal site.

The DMRP studies (Tatem, 1984; Sweeney, 1978; Tatem and Johnson, 1978) examined various environmental samples taken before, during, and nine months after the disposal operation of February-March 1976. Bathymetric surveys were also made by the Corps to construct bottom contour maps of the inner Elliott Bay disposal area which indicated little or no change in the disposal area between 1976 and 1979.

Currents were measured to determine whether the currents were sufficiently strong to transport the sediment. It was observed that the sediment was generally cohesive and difficult to move. The data indicated that the currents were weak, moved primarily in response to tidal fluctuations, and apparently did not move much of the sediment; therefore, the area could be characterized as depositional rather than erosional. It is possible that some silt and clay could have been suspended or resuspended for a small percentage of the time; however, bottom photographs were very clear, indicating little resuspension of sediment particles.

An accidental spill of PCB occurred in the Duwamish River in September 1974 and settled in bottom sediments. The contaminated sediments were removed during February and March, 1976 using special dredging techniques designed to minimize release of the material to the water. Some of the contaminated material was placed at the experimental test site, which coincidentally falls within the inner Elliott Bay ZSF. The PCB was used as a tracer of the sediment allowing documentation of the location and movement of the dredged material.

A comparison of data from the DMRP study on PCB levels in the upper 10 centimeters of sediment at the center of the disposal grid with data from the DOTS study indicated that no major changes in overall PCB levels occurred through 1980. In general, the PCB analyses supported the results of the sediment texture analyses and indicated that the dredged material mound had not changed since the DMRP studies.

During September 1974, a core was retrieved from the Fourmile Rock disposal site (Schell et al., 1976). A visual examination of this core indicated depletion of fine particles in the upper layers. The core was sectioned and dated by Lead-210 (210Pb) dating techniques and then analyzed for trace metals. Trace metal concentrations versus depth in the core and 210Pb values were used to determine the sedimentation rate.

For determination of sedimentation rates, the cores were divided into sections, and the 210Pb activity in each section was determined by alphaspectroscopy. Schell et al. (1976) suggested that the finer material, containing most of the 210Pb, was carried away by bottom currents as indicated in the first section of the curve. They cited the trace metal profiles presented in Figure II.7-7 as further evidence of the erosion.

TABLE I.2-1 MAJOR DREDGING AREAS AND SUBAREAS LOCATED IN THE PHASE I CENTRAL PUGET SOUND REGION.

Location	Major Dredging Areas
Port Gardner	East Waterway
	Lower Snohomish
	Upper Snohomish
Elliott Bay	Lower Duwamish
	Upper Duwamish
	Duwamish Turning Basin
	Lakes: Kenmore/Sam. R.
	Lakes: Lake Washington
	Lakes: Lake Union
	Lakes: Lake Wash. Canal
	Sinclair Inlet
	Eagle Harbor
Commencement Bay	Hylebos Waterway
	Blair Waterway
	Sitcum Waterway

TABLES I.2-2 PUGET SOUND DREDGED MATERIAL INVENTORY FOR THE PHASE I AREA (SEATTLE, TACOMA, EVERETT) 1970-1985. ALL VOLUMES ARE EXPRESSED IN CUBIC YARDS.

A. Totals

Total volume dredged	16,850,000 cubic yards
Total volume disposed at unconfined open-water sites	6,758,000 cubic yards
Total volume disposed at:	
Port Gardner	692,000 cubic yards
Elliott Bay	4,598,000 cubic yards
Commencement Bay	782,000 cubic yards

	Corps of Engineers Projects	Port Projects	Other Projects
B. Project Type			
Total volume dredged (cubic yards)	5,775,000	4,635,000	6,480,000
Total volume disposed to open water (cubic yards)	2,167,000	1,389,000	3,202,000
Total volume disposed upland or nearshore (cubic yards)	3,588,000	3,246,000	3,257,000

C. Disposal Method

	Disposal Methods for Corps of Engineers Projects			
	1970-1979		1980-1985	
	Volume	Percent	Volume	Percent
Water	818,214	24	1,027,227	54
Upland/Nearshore	2,544,766	76	887,274	46

TABLE I.2-3 PHASE I AREA 15-YEAR PROJECTIONS (1985-2000) OF TOTAL DREDGING VOLUMES

Location	Dredging Area	Project Volume (cubic yards)
Port Gardner and Vicinity	East Waterway	3,552,000[1]
	Lower Snohomish	2,321,000
	Upper Snohomish	2,175,000
	All other areas	195,000
	Subtotal	8,243,000
Elliott Bay and Vicinity	Lower Duwamish	4,812,000[2]
	Upper Duwamish	2,021,000
	Duwamish Turning Basin	612,000
	Lakes: Kenmore/Sam. R.	114,000
	Lakes: Lake Washington	1,368,000
	Lakes: Lake Union	5,000
	Lakes: Lake Wash. Canal	80,000
	Sinclair Inlet	200,000
	Eagle Harbor	115,000
	All other areas	1,198,000
	Subtotal	10,525,000
Commencement Bay and Vicinity	Hylebos Waterway	216,000
	Blair Waterway	2,936,000[3]
	Sitcum Waterway	56,000
	All other areas	166,000
	Subtotal	3,929,000
	Total	22,697,000

Reference: Projections made by U.S. Army Corps - Seattle District,
presented in the PSDDA cost analysis.

1/Includes U.S. Navy homeport project.
2/Includes Duwamish widening and deepening project.
3/Includes Blair/Sitcum navigation improvement project.

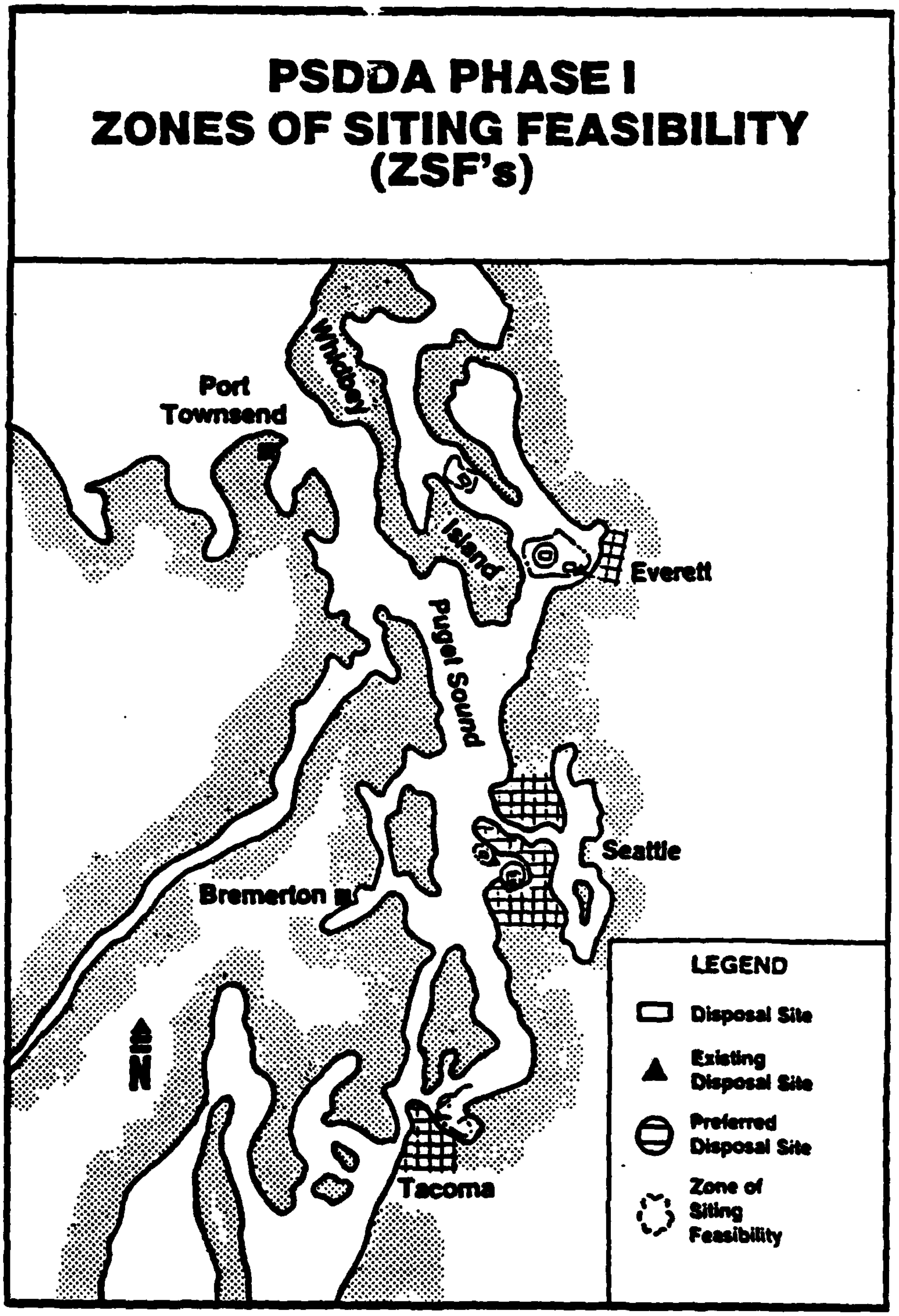


Figure I.2-1 PSDDA Phase I Zones of Siting Feasibility (ZSFs). (Source: Corps)

PART II. IDENTIFICATION OF UNCONFINED OPEN-WATER DISPOSAL SITES

1. OVERVIEW OF DISPOSAL SITE SELECTION PROCESS

The site selection process used by PSDDA utilized existing information in combination with field studies to identify preferred and alternative disposal sites. The approach used is similar to that described in the EPA and Corps workbook entitled "General Approach to Designation Studies for Ocean Dredged Material Disposal Sites" (EPA/Corps, 1984). Steps of the site selection process were as follows:

(1) Define general siting philosophy. This step addresses disposal philosophy (i.e., whether sites should be dispersive or nondispersive), general siting locations (i.e., ocean, strait, or sound), and the number of disposal sites.

(2) Identify selection factors to delineate Zones of Siting Feasibility (ZSFs). This step uses existing information on biological resources and human use activities to identify general areas where disposal sites might be appropriately located.

(3) Conduct field studies on the ZSFs. Field and model studies are conducted to fill key data gaps and gather information on the physical and biological conditions of the ZSFs. Since these studies were conducted to check the general condition of the ZSFs, they are sometimes referred to as "checking studies".

(4) Identify preliminary sites within the ZSFs. Information from the ZSF studies is used to identify preliminary locations for disposal sites within the ZSFs.

(5) Conduct field studies on the sites. Field and model studies are conducted to obtain needed physical and biological information for the preliminary sites. These studies are referred to as "site-specific studies".

(6) Identify preferred sites. Information from the site-specific studies is used to identify preferred and alternative sites.

Existing DNR disposal sites were considered in the disposal site selection process if they met certain site selection factors. All cooperating agencies in PSDDA agreed early on that no special *a priori* consideration would be given to the existing sites, because of human use conflicts and environmental concerns with past dredging and disposal protocols. An objective site

selection process was used to minimize environmental and human usage conflicts as much as possible, and existing sites adequately meeting the site selection factors and constraints were given equal consideration with other potential sites.

1.1 Disposal Philosophy

Early in the site selection process discussions arose concerning the merits of dispersive versus non dispersive sites. The initial consensus was to consider all types of sites, including river deltas. The factors in Table II.1-1 were ranked according to their importance in selecting dispersive/non-dispersive sites. They were ranked high concern (+), medium concern (x), or low concern (-).

It was soon determined that unconfined open-water disposal sites in the Phase I area should be relatively nondispersive rather than dispersive in nature. Placing dredged material in nondispersive sites gives site managers the ability to maintain control and accountability over site conditions. This is particularly important when chemical contaminants may be present in the dredged material and it is necessary to minimize the exposure of important resources.

Monitoring of the stability of a dredged material deposit is important. If material is contained within a stable, mounded deposit then the contaminants are not readily available to the environment beyond the margins of the disposal site. One of the cost important concepts of disposal management is the classification of disposal sites as containment (non-dispersive) or dispersive sites. This classification is then reflected in the overall management of the site. If it is concluded that the dredged material will generally stay within the boundaries of a disposal site then monitoring of disposal impacts and capping (if required for remedial action) is possible. However, if the site is a dispersive site then point dumping or other techniques to limit the spread of material are not warranted and monitoring of impacts is much more difficult simply because of a much larger zone of potential impact. For these reasons the general policy for designation of disposal sites has been to find areas where discharged dredged material will be relatively stable.

The general philosophy that PSDDA chose for the Phase I site selection was:

- Disposal of dredged material should avoid unacceptable adverse resource impacts.
- Only material suitable for unconfined disposal should be allowed at the sites.
- Sites should be located in a relatively non-dispersive environment.

- o When site use is discontinued, eventual recovery to ambient conditions should occur.
- o Site should have no unacceptable adverse impacts on foodfish, shellfish, and marine mammals.
- o Minimize interference on human uses. (Shipping lanes and anchorages may have Coast Guard restrictions).
- o Full compliance with 404(b)(1) guidelines.

The ability to monitor disposal site operations, to modify disposal practices, and to conduct any necessary site remedial actions, are all advantages of the nondispersive siting philosophy. If dispersive sites are functioning correctly, monitoring and assessment of impacts is extremely difficult. It is expected that any unacceptable adverse impacts can be identified and controlled and, therefore, that public acceptance will be greater, with nondispersive rather than dispersive siting.

1.1.1 Assumptions--

Assumptions made by DSWG in selecting areas suitable for disposal sites are discussed later in this Appendix. However, they are listed here for conciseness. The major assumptions were:

(1) Dredged material will be dumped from bottom dump barges.

(2) The dredged material will be suitable for unconfined open-water disposal.

(3) It is preferable that the dredged material generally remain within the chosen disposal site, i.e., a non-dispersive site is preferred over a dispersive site.

(4) An area was considered relatively non-dispersive if the peak 1% current speed was less than 25 centimeters per second and if the sediments had small grain size; and statistically elevated (i.e., greater than 1.96 SND*) volatile solids, biochemical oxygen demand, and water content for values collected for that depth.

(5) These assumptions were applied only when biological resource values were generally low.

*SND = Standard Normal Deviate

1.1.2 Objectives--

The specific objectives of the DSWG in the Phase I area were to select disposal areas reasonably accessible to major urban areas where there is substantial dredging activities.

1.2 General Siting Locations

General areas available for unconfined, open-water disposal include the Pacific Ocean, the Strait of Juan de Fuca, and Puget Sound. Discussion of each area follows.

1.2.1 Ocean Disposal--

While disposal of dredged material within the waters inside the baseline from which the territorial sea is measured is governed by the Clean Water Act and Section 404(b)(1) guidelines, disposal beyond the baseline, in the open ocean, is regulated by guidelines developed under the Marine Protection, Research and Sanctuaries Act (Public Law 92-532, as amended). The ocean dumping regulations require application of specifified criteria to evaluate dredged material and the use of formally designated disposal sites. At the present time, there are no designated ocean disposal sites in the Pacific Ocean west of Cape Flattery.

The costs associated with barge transport of dredged material to the ocean are extremely high. Estimated unit costs of barge transport per cubic yard ($/c.y.) to potential ocean disposal sites 10 or 50 nautical miles off Cape Flattery (the Cape is approximately 124 nautical miles from Elliott Bay) range as follows: Port Gardner: $31.55-$41.55/c.y.; Elliott Bay: $33.05-$43.05/c.y.; and Commencement Bay: $38.25-$48.25/c.y. (EPTA, 1987). These costs are in addition to dredging costs.

Prior to any disposal, permitting and EIS procedures similar in nature to PSDDA would be required for site designation and use. Additionally, dredged material evaluation procedures for ocean disposal are similar to those which are being developed by PSDDA. Therefore, it is highly unlikely that disposal of greater quantities of dredged material at unconfined, open-water disposal sites would be considered acceptable; and environmental benefits or savings to offset transportation costs would not be realized. Additionally, nondispersive sites could likely not be found, necessitating use of dispersive sites.

Another problem with conducting disposal operations in the open ocean environment results from high winds/waves and storm activity, which occur during the fall, winter, and early spring seasons.

Therefore, ocean disposal is a method that is not currently available within a cost effective distance from Port Gardner, Elliott Bay, and Commencement Bay. This method is therefore not considered to be a reasonable option because of decreasd safety, increased costs and no offsetting environmental benefits. EPTA, Part II, Section 10.4 contains an additional discussion and cost analysis for the ocean disposal method.

1.2.2 Disposal in the Strait of Juan de Fuca--

Though disposal of dredged material in the Strait of Juan de Fuca is regulated under Section 404 of the Clean Water Act, the concerns for this option are similar to the ocean disposal option. Dredged material evaluation procedures would be similar, assuming a nondispersive site could be found. Additionally, disposal in this area, especially if located adjacent to the U.S.-Canadian border, may require added coordination with the Canadian authorities.

The transport costs for this option are also very high. Estimated unit costs ($/c.y.) of barge transport from the Phase I areas to a high potential disposal site at the mouth of Cape Flattery within the Strait of Juan de Fuca are: Port Gardner: $29.30; Elliott Bay: $30.80; and Commencement Bay: $36.30. And frequent winter storms would cause disposal operations to be more hazardous than the more sheltered areas of Puget Sound.

Therefore, disposal in the Strait is a method that is not currently available within a cost effective distance from Port Gardner, Elliott Bay and Commencement Bay, and is not considered to be a reasonable option because of decreased safety and lack of offsetting environmental benefits. EPTA, Part II, Section 10.4 contains an additional discussion and cost analysis for the Straits disposal method.

1.2.3 Puget Sound--

The remaining potential open-water disposal sites are located within the PSDDA Phase I and II study areas. The general similarity of physical and biological conditions in the various parts of Puget Sound argues against the need to transport Central Puget Sound (Phase I area) dredged material to either the northern or southern portions of the Sound (Phase II areas). There is no discernible gain in environmental benefits that will offset increased costs.

Therefore, only dredging and open-water disposal sites within the confines of the PSDDA Phase I area are addressed in detail. PSDDA will identify additional disposal sites as a separate study for the Phase II area.

1.3 Number of Sites

To determine the number of sites needed, the major areas of dredging were identified for the Phase I area. Review of dredging records compiled for PSDDA (see EPTA for detailed dredging information) indicates that the largest quantities of dredged material are generated in the Everett, Seattle, and Tacoma areas. Dredging projects throughout the remainder of Central Puget Sound are less frequent and generate substantially less volume of material. These three major areas are located at approximately equal distances from each other on a north-south line. Additionally, each area contains low-energy environments which would likely provide nondispersive sites.

PSDDA considered one or two, three, and four or more regional disposal sites for the Phase I area. The one or two disposal sites option, although affecting less total bottom acreage, would have significant economic repercussions for the particular major dredging area(s) operating without a nearby disposal site. Though no cost difference would be incurred by those Port facilities closest to the disposal site, greater costs would be incurred by others.

The four or more disposal sites option is also considered undesirable. Little economic benefit would be realized by designating sites outside the major dredging areas, and site management responsibilities and costs would be increased. Additional areal spread of sediments would result in added environmental effects.

Historically, dredged material disposal has occurred at the three major urban embayments within Central Puget Sound. This precedent, in combination with the reasons described above, led PSDDA to decide that three sites should be found for Phase I, one for each major dredging area.

TABLE II.1-1 SELECTION FACTORS AND THEIR RANKING FOR DISPERSIVE AND NON DISPERSIVE SITES.

Factors	Dispersive	Non Dispersive
Navigation Lanes	+	+
Biological Resources (food & shellfish)	+	+ (Aquatic habitat)
Monitoring Compliance	-	+
Economic Haul	x	x
Remedial	+	x
Aesthetics	-	x or +
Other Use (cable crossings, anchorages)	+	+ (Fish & Trawl areas)
Sediment Type	?	+
Current Velocity	+	+
Wave & Current Direction	+	+
Pollutant Loading	+	+
Water Quality	x	x
Bathymetry	-	+

Source: Minutes of DSWG Meeting Number 1, dated 4 April 1985.

2. ZONES OF SITING FEASIBILITY (ZSFs) IN PHASE I AREA

2.1 Identification of the ZSFs

Zones of Siting Feasibility (ZSF) are those areas which may have the potential to accomodate open-water disposal activities based on existing information. In general, ZSFs are areas which have the least conflict with the siting factors of concern. The process utilized to identify ZSFs involved four discrete steps:

Step 1. Define general ZSF selection factors.

Step 2. Define and map specific ZSF selection factors.

Step 3. Apply constraints to the identified ZSFs.

Step 4. Prioritize ZSFs for purposes of field studies.

These steps are further described below, and are addressed in detail in Section II.3 of this Appendix.

2.1.1 General ZSF Selection Factors--

Three general ZSF selection factors were identified early in the PSDDA study. It was determined that ZSFs should, to the maximum extent possible:

- o Avoid high energy areas that would disperse dredged material significantly beyond the disposal site area.
- o Avoid unacceptable adverse impacts on foodfish, shellfish, marine mammals, and marine birds.
- o Minimize interference with human uses to the lowest practicable level.

2.1.2 Specific ZSF Selection Factors--

The three general ZSF selection factors were further defined by nineteen specific selection factors. Most of these factors are identified in Federal and State regulations relating to dredged material disposal sites located in water. The specific factors were mapped and overlayed to display areas where siting might occur with a minimum of conflict (Table II.2.1). See Exhibit B for a detailed description of site selection factors and maps. These factors are:

TABLE II.2-1. SPECIFIC FACTORS FOR IDENTIFICATION OF ZONES OF SITING FEASIBILITY

1. Navigation activities
2. Recreational uses
3. Cultural sites
4. Aquaculture facilities
5. Utilities
6. Scientific study areas
7. Point pollution sources
8. Water intakes
9. Shoreline land use designations
10. Political boundaries
11. Location of dredging areas
12. Beneficial uses of dredged material
13. Fish/shellfish harvest areas
14. Threatened and endangered species
15. Fish/shellfish habitat
16. Wetlands, mudflats and vegetated shallows
17. Bathymetry
18. Sediment characteristics
19. Water currents

2.1.3 Apply Constraints to Identified ZSFs--

Additionally, the following constraints were imposed on ZSF boundaries by PSDDA:

First, the ZSF should be located a minimum water surface distance of 2,500 feet from adjacent shorelines to provide a buffer from noise and adverse environmental effects to the shore.

Second, the ZSFs should be buffered by a minimum distance of 2,500 feet as measured along the water surface from vulnerable biological resources.

Third, the ZSFs should be located in water depths greater than 120 feet. Water depths of less than 120 feet are generally more biologically productive and of major importance to many of Puget Sound's important commercial fish and shellfish species.

And fourth, the ZSFs should be located in water depths of less than 600 feet. Based on model results, water depths greater than 600 feet could result in substantially more dispersion of the dredged material during descent through the water column.

It is important to note that the selection factors and constraints were not considered or applied as inviolate standards. This is primarily because they were being used with existing and available information. As studies gathered new information about the ZSFs, adjustments to boundaries, and later to site locations, were made as necessary.

2.1.4 Prioritization of ZSFs for Purposes of Field Studies--

ZSFs were further divided into priority 1 and 2 rankings based on their proximity to major dredging areas (Figs. II.2-1 a&b). The rankings served to identify areas that would receive first consideration for studies to locate potential sites. If acceptable sites could not be found, priority 2 ZSFs would be considered. Priority 1 ZSFs are less than ten nautical miles and priority 2 ZSFs are greater than ten nautical miles from major dredging areas, which reflects a consideration of economic factors.

2.2 Description of the ZSFs

The priority 1 ZSFs identified from this process are located in Port Gardner, inner Elliott Bay, outer Elliott Bay, and Commencement Bay (Fig. II.2-1). The limited information available for the Port Gardner ZSF suggested the need to identify a backup ZSF, pending information to be gathered from field studies. Therefore, a Priority 2 ZSF in Saratoga Passage was also included for detailed studies. Priority 2 ZSFs other than Saratoga Passage were not studied in detail since field studies of the priority 1 ZSFs showed them to be acceptable. The ZSFs are described below.

After all of the field studies the final preferred and alternative sites were chosen. These sites are shown on many figures as a convenience to the reader, so that the final sites can be seen with the data. Table II.2-2 gives these disposal site location coordinates for each ZSF.

2.2.1 Saratoga Passage ZSF--

The Saratoga Passage Priority 2 ZSF was located immediately south of the mouth of Holmes Harbor. Factors determining the boundaries of this ZSF were vessel traffic, shellfish populations, and finfish harvesting to the northeast; finfish harvesting to the southeast; cable routes and crab populations to the southwest; and groundfish habitats in the northwest.

2.2.2 Port Gardner ZSF--

The Port Gardner ZSF was selected using the constraints of water depth (i.e., deeper than 120 feet and shallower than 600 feet) and providing a 2,500-foot buffer zone adjacent to the shore. Limited data existed which indicated that important fish and shellfish (notably Dungeness crab) resources might exist in all or portions of the ZSF. Given the paucity of data, PSDDA decided to conduct field studies of the ZSF to determine the seasonally dependent spatial distribution of these resources as a positive check on potential resource conflicts. In the event serious conflicts were found to exist, then the Saratoga Passage ZSF could be utilized as an alternative site. The existing Port Gardner disposal site was only partially located within the ZSF and half of the site was outside the ZSF within the 2,500-foot buffer.

2.2.3 Elliott Bay ZSFs--

The northern ZSF in Elliott Bay is located off Fourmile Rock and is shaped roughly like a football. The southwest boundary of the football was constrained by tugboat routes and cable crossings, while the inshore boundary was determined by the 120-foot depth limitation and an anchorage area. The western corner of the ZSF encompassed the existing DNR disposal site known as Fourmile Rock.

The inner Elliott Bay ZSF is located north of the mouth of the Duwamish River. The boundaries of the inner Elliott Bay ZSF were determined by ferry crossings on the north, anchorage areas and navigation lanes to the south and east.

2.2.4 Commencement Bay ZSF--

Boundary delineations for the Commencement Bay ZSF were largely determined by the water depth criteria (between 120 feet and 600 feet) and the 2500 foot shoreline buffer. Biological resource conflicts were minimal within the ZSF boundary. The existing DNR disposal site is located within the priority 1 ZSF.

2.3 Literature Review

2.3.1 Bibliography--

Parallel to the preparation of the overlays, an intensive literature search was made to compile the information that was used to construct the maps. Due to the large number of citations, they have not been included in this technical appendix; however, they can be found in the reports entitled, "Bibliography and Maps Pertinent to the Selection of Open Water Dredge Disposal Sites in the Greater Puget Sound Region" (Evans-Hamilton, Inc., 1985), and Evans-Hamilton, Inc., (1988), "The Location, Identification and Evaluation of Potential Submerged Cultural Resources at Three Puget Sound Dredged Disposal Areas" which are on file at the Corps Seattle District library. The literature survey resulted in a bibliography of references to existing maps containing information relevant to the selection of ZSFs. The geographic area covered included Puget Sound, the Strait of Juan de Fuca east of Port Angeles, and the Strait of Georgia south of the Canadian border.

2.3.2 Environmental Studies Review--

As part of the evaluation process a review of existing information was undertaken which helped to characterize these zones. This review consisted of an evaluation of published literature as well as unpublished data. The effort was initiated and guided by, discussions with individuals representing city, state and Federal agencies, academic institutions, and private consulting organizations known to have expertise in Puget Sound history, biology, chemistry, and physical oceanography.

The bibliographic entries were surveyed for information concerning the ZSFs. Screening of these sources was aided by discussions with many individuals. They suggested other published sources, as well as unpublished data and draft reports, which might be applicable to the ZSFs. A summary of the review findings is given by Cooper Consultants (1986). In addition, Exhibit C describes investigations of significant historical properties.

2.4 ZSF Field Studies

Though initial overlay mapping identified locations of ZSFs, this mapping and literature review revealed several key information gaps for these areas. In order to define characteristics of potential disposal sites within those ZSFs, PSDDA undertook a series of field studies, including side scan sonar, chemical and biological studies.

Data collection activities were focused on those areas where information was lacking. Review of the mapping data and priority 1 ZSF selection indicates that little or no conflict with human, shoreline and shallow water uses and values would

occur. However, the same review highlighted the lack of physical and biological data for all of the priority 1 ZSFs. Therefore, studies focused on two critical issues:

First, what is the depositional/erosional (nondispersive/dispersive) nature of areas within each ZSF? Can acceptable nondispersive sites be identified?

And second, what is the value of the priority 1 ZSFs to biological resources of concern (i.e., crab, bottomfish and shrimp). The focus was placed on species which would be in direct contact with the dredged material on the sea floor.

(1) Survey of Bottom Conditions. A submersible remote operational vehicle, named MANTA, collected physical bottom data with a sidescan sonar, and attempted to obtain data on biological resources through use of a video camera and 35 millimeter stereo still cameras. This survey unfortunately was undertaken immediately following a large storm event in November of 1985. Turbidity in all deep Central Puget Sound water at this time was extemely high. Still photographs and video efforts were of little use. However, the sidescan sonar effectively characterized bottom contours and identified larger features on the bottom.

(2) Remote Ecological Monitoring of the Seafloor (REMOTS) Survey. The REMOTS device allows sediment profile imagery of photographs of the upper 20 centimeters (7.9 inches) of the seafloor bottom sediments. Van veen grab samples were collected and archived for potential ground truthing of the REMOTS observations. Computer imaging analysis of REMOTS photographs provided information on physical and biological (infaunal benthos) characteristics. The REMOTS survey described benthic habitat boundaries and identified general areas that were depositional in nature.

(3) Depositional Analysis of the Sediments. The objective of the depositional analysis was to locate areas within the ZSF where sediments tend to deposit rather than erode. Previous work by Word et al. (1984a) indicated that sediments within Puget Sound tend to accumulate where existing sediments meet the following four conditions when compared to sediments at similar depths: (1) small grain size; (2) statistically elevated volatile solids; (3) statistically elevated water content; and (4) statistically elevated biochemical oxygen demand. Over 200 stations were occupied to collect sediment samples for this technique. Study results were used to identify areas that were most non-dispersive within each ZSF, and Section II.5 of this Appendix describes the methods and results of this study for each ZSF.

(4) Current Velocity Studies. Current strengths at each ZSF were determined by a combination of: (1) review of historical field data (including current meter work undertaken by PSDDA and the Navy in Port Gardner), (2) predicted current velocities from a mathematical model, (3) predicted current velocities from a physical hydraulic model, and (4) current meter moorings placed by PSDDA at the existing disposal sites in Elliott Bay and Port Gardner.

Based on these analyses, predicted current velocities were identified and mapped. Results indicate that all of the priority 1 ZSFs and the Saratoga Passage priority 2 ZSF are in relatively low current velocity areas. Material deposited at sites in these ZSFs is not expected to significantly move offsite.

TABLE II.2-2 PSDDA DISPOSAL SITE LOCATION COORDINATES

PHASE I
JANUARY 1987

Location	Preferred		Alternate	
	Latitude	Longitude	Latitude	Longitude
Saratoga Passage	None		48°N 5.43'	122°W 27.35'
Port Gardner	47°N 58.86'	122°W 16.67'	47°N 58.26'	122°W 15.55'
Elliott Bay	47°N 36.03'	122°W 21.34'	47°N 37.09'	122°W 24.85'
Commencement Bay	47°N 18.22'	122°W 27.84'	47°N 18.72'	122°W 27.95'

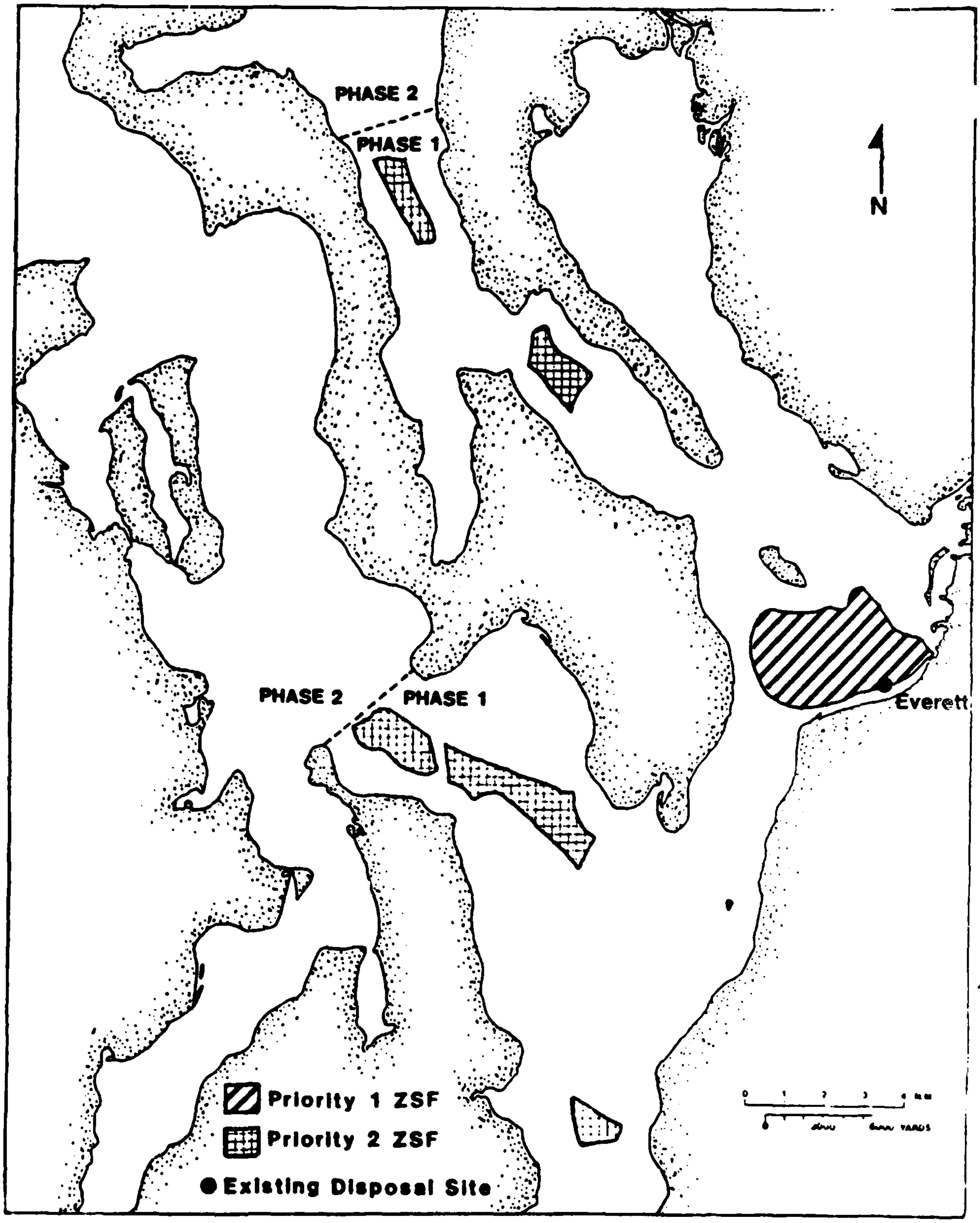


Figure II.2-1A Locations of the priority (1) ZSFs, priority (2) ZSFs, and the existing disposal sites in the northern portion of PSDDA Phase 1 area

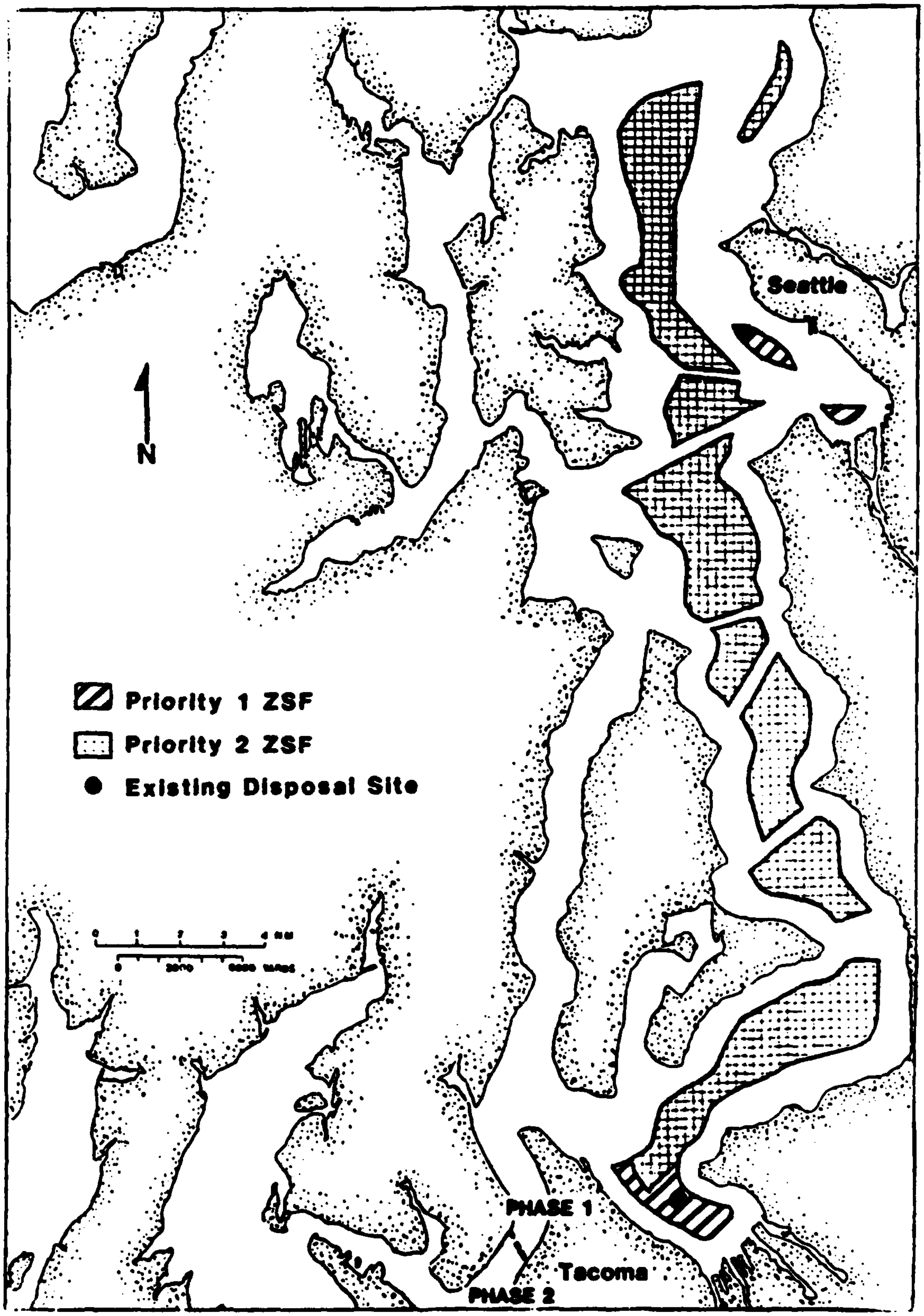


Figure II.2-1B Locations of the priority (1) ZSFs, priority (2) ZSFs, and the existing disposal sites in the southern portion of PSDDA Phase 1 area.

3. PRELIMINARY DISPOSAL SITE IDENTIFICATION

Using information obtained via ZSF identification and field studies, preliminary disposal site locations within the ZSF were identified. Two factors were emphasized in locating the disposal sites: (1) a low abundance of commercially important animals (i.e., small numbers of crab, shrimp, and bottomfish); and (2) the presence of a relatively nondispersive area (i.e., sediment and current characteristics indicating that sediments would stay at the disposal site).

3.1 Selection Process

To evaluate the prime criteria a selection process was undertaken in the three steps outlined below.

(1) Size of the Disposal Site. The size of the disposal site was related to the bottom physical impact that would result from repeated dumps within an 1800 foot diameter disposal zone. The impact area was evaluted using a numerical model and field data. Using Puget Sound data, the Corps Waterways Experiment Station in Vicksburg, Mississippi, performed a simulation study depicting dredged material disposal in an unconfined open water environment. The model simulated the passage of dredged material through the water column for varying water depths, current speeds, and sediment types to predict the behavior of material during future disposal operations. The simulated conditions were representative of those in Puget Sound - sediment types that are routinely dredged and disposed of were simulated; depths ranged from 100-800 feet; and tidal currents ranged from zero to two knots (3.38 feet per second). See Figure II.3-1 for typical site parameters.

(2) Biological Resources. The biological resources within each ZSF were mapped using a number of approaches. In the fall of 1985 an attempt was made to photograph the bottom sediments in four of the ZSFs (not Commencement Bay) using a towed video system called MANTA. Unfortunately no visible results were gained because of poor visibility

Additionally, vertical sections of the upper 0-16 centimeters (0-6.3 inches) of the bottom sediments were photographed using the REMOTS system (see Cooper Consultants, 1986). The REMOTS system can detect sediment thicknesses up to approximately 18 centimeters (7 inches) deep, which is limited by the prism window height. Because the REMOTS images in Puget Sound have not been compared with conventional taxonomic identifications there were some differences amongst

experts regarding the biological interpretation (mudclasts and biological community) of the REMOTS photographs. However, comparisons between REMOTS and conventional quantitative benthic community analyses in Long Island Sound and in the Chesapeake Bay have shown generally close agreement in interpretation between the two techniques. A recent study (Lunz, 1986) comparing REMOTS and Benthic Resources Assessment Technique (BRAT) off the coast of Massachusetts in 300 feet of water showed very close agreement in biological interpretation. Lastly the BRAT boxcore data collected in Puget Sound agree with the general community type assessments accomplished with the REMOTS imagery. PSDDA chose tentative sites based on available information concerning the strength of the tidal currents, and REMOTS data, along with the depositional analysis to plan sampling station strategy for BRAT field studies and REMOTS data was used to describe sites in the EIS.

After these selections were made, site specific studies were conducted including trawls for the presence of crab, shrimp, and bottomfish, and boxcore sampling was used to quantify and assess the bottomfish food habitat values with the Benthic Resources Assessment Technique (BRAT).

(3) Non-Dispersive Probability. The likelihood that dredged material would remain within the disposal site was evaluated using a number of approaches.

First, the maximum currents within each ZSF were mapped using historical data, and some data recently acquired by the Corps and the U.S. Navy using current meters. These results were compared with speeds that were observed during special field studies in Dana Passage (Sternberg and Collias, 1973) to mobilize and transport sediment. At speeds above approximately 0.5 knot dredged material was observed to be resuspended and transported. Because of the sparsity of historical data, a two-dimensional numeric model was calibrated for Puget Sound by the Corps Waterways Experiment Station. Modeling results allowed some interpolation between more widely spaced field data.

Second, four sediment characteristics within the ZSFs were mapped (grain size, sediment biochemical oxygen demand, percent moisture, and percent volatile solids) using a technique called "depositional analysis" (Striplin et al., 1987). An area was classified as non-dispersive or "depositional" in character if its sediments had the following characteristics: small grain size; high oxygen demand; high percent water; and high volatile solids.

Thirdly, the fate of resuspended materials was evaluted within the ZSFs to avoid impacts downstream on sensitive habitats.

Maps developed from these determinations were overlayed to identify disposal sites that best satisfied the desired site conditions.

3.2 Preliminary Sites

Preliminary sites were identifed in all the priority 1 ZSFs. As a result, two sites were specified in Port Gardner, (Fig. II.3-2), two sites in Elliott Bay (Fig. II.3-3), and two sites in Commencement Bay (Fig. II.3-4). Additionally, a site was also identified in the Saratoga Passage priority 2 ZSF (Fig. II.3-5). Though only one site will be selected for each of the three areas, the extra sites serve as alternatives and backups should site studies indicate a problem with one of the sites. Detailed descriptions of site selection process are described later in this Appendix for each site. Preferred and alternative sites in the Commencement Bay ZSF were identified based on results of ZSF and site-specific studies.

3.3 Site Specific Field Studies

Additional studies were conducted for the preliminary sites to define the size of the bottom impact area and to refine site location relative to food web values of these areas.

(1) Numerical Dump Model. To assist in establishing the size and location of the disposal sites, a numerical model, originally developed for EPA, and later refined by the Corps' Waterways Experiment Station, was used to estimate the depositional pattern caused by the disposal of a single bargeload of dredged material. The model was run for two types of dredged material at several depths and current speeds. Results from this model were combined with an estimate of the surface disposal zone diameter to provide an initial assessment of the sediment deposition pattern that might be caused by repeated disposals within a site. The model results indicate that the impact of any one barge load (1,500 c.y.) of material is confined to a relatively small area. In 400 feet of water the descending cloud is approximately 250 feet in diameter when it hits the bottom, occurring 30 seconds after disposal is initiated. The collapsing cloud then spreads out in all directions. Ten minutes later essentially all of the material is deposited on the bottom within a 1,000-foot radius of the drop point. The thickness of the deposited material varies from about 0.3 inches at

the center of the disposal mound to 0.04 inches at the edge. These results assume a worst-case spread of a completely slurried load. Dredged material with cohesive clumps would not spread as far or as thinly. The final size, orientation, and configuration of the disposal sites are not significantly affected by the materials deposited from any single barge disposal, but are governed by the total amount of material being deposited, sediment bulking factors, stable side slope characteristics of the sediments, existing bottom topography and consolidation characteristics of both the bed and dredged material. These model studies were used to define the bottom impact area, described below, for each of the sites.

(2) Crab, Shrimp, and Bottomfish Trawling Studies. The distribution and relative abundance of important commercial Dungeness crab, shrimp, and bottomfish resources were mapped in and around all priority 1 ZSFs from data obtained during seasonal sampling cruises. The objective was to evaluate the importance of the ZSFs in general to these important commercial natural resources, and to minimize impacts as much as possible as part of the site selection process by helping to identify areas of lowest habitat value.

Results indicated disposal sites can be located within the priority 1 ZSF yet avoid significant conflict with each of these resources.

(3) Food Web Study. Benthic resources within and adjacent to each of the preliminary disposal sites under consideration were evaluated in terms of their food support potential to bottomfish resources. A procedure called the Benthic Resources Assessment Technique (BRAT) developed by the U.S. Army Waterways Experiment Station (Lunz and Kendall, 1982), was used to quantify the food value of bottom-dwelling organisms within soft-bottom habitats to bottom-feeding fishes. The BRAT estimates which organisms at a given site are both vulnerable and available to selected fish species.

Different species of bottom-feeding fishes can detect, capture, and ingest only a portion of the available benthos. They will consume different prey at different locations and seasons, reflecting the availability of vulnerable prey. In the BRAT, vulnerability is taken to be a function of the size of the benthic food item, and availability of the prey's location below the sediment-water interface. Both factors are estimated from an examination of the diets of target predatory fish, and confirmed by a parallel examination of vulnerable and available prey in the local benthic environment. Food web linkages between benthic organisms, key fish and shellfish, and

ultimately humans via commercial and recreational fisheries offers resource managers a way of assigning comparative resource values to alternative disposal sites. Section II.9 of this Appendix contains a complete description of the methods and results of this procedure.

As with the trawling studies, BRAT confirmed that resource values at the potential disposal sites within the priority 1 ZSFs and at the Saratoga Passage Priority 2 ZSF were generally equal to or lower than surrounding areas. Consequently, adjustments to site locations were not considered necessary.

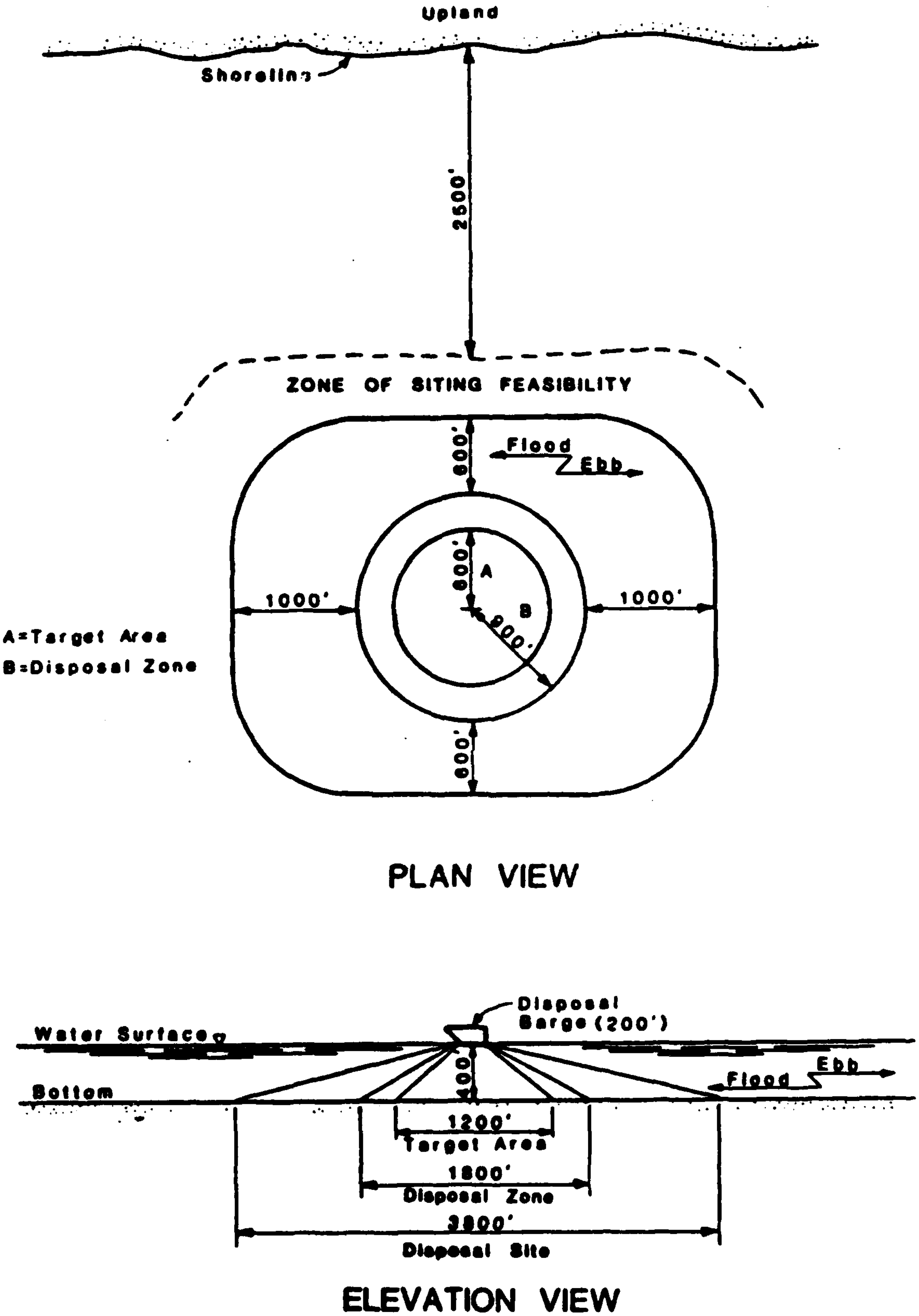


Figure II.3-1 Typical disposal site parameters. (Source: Corps)

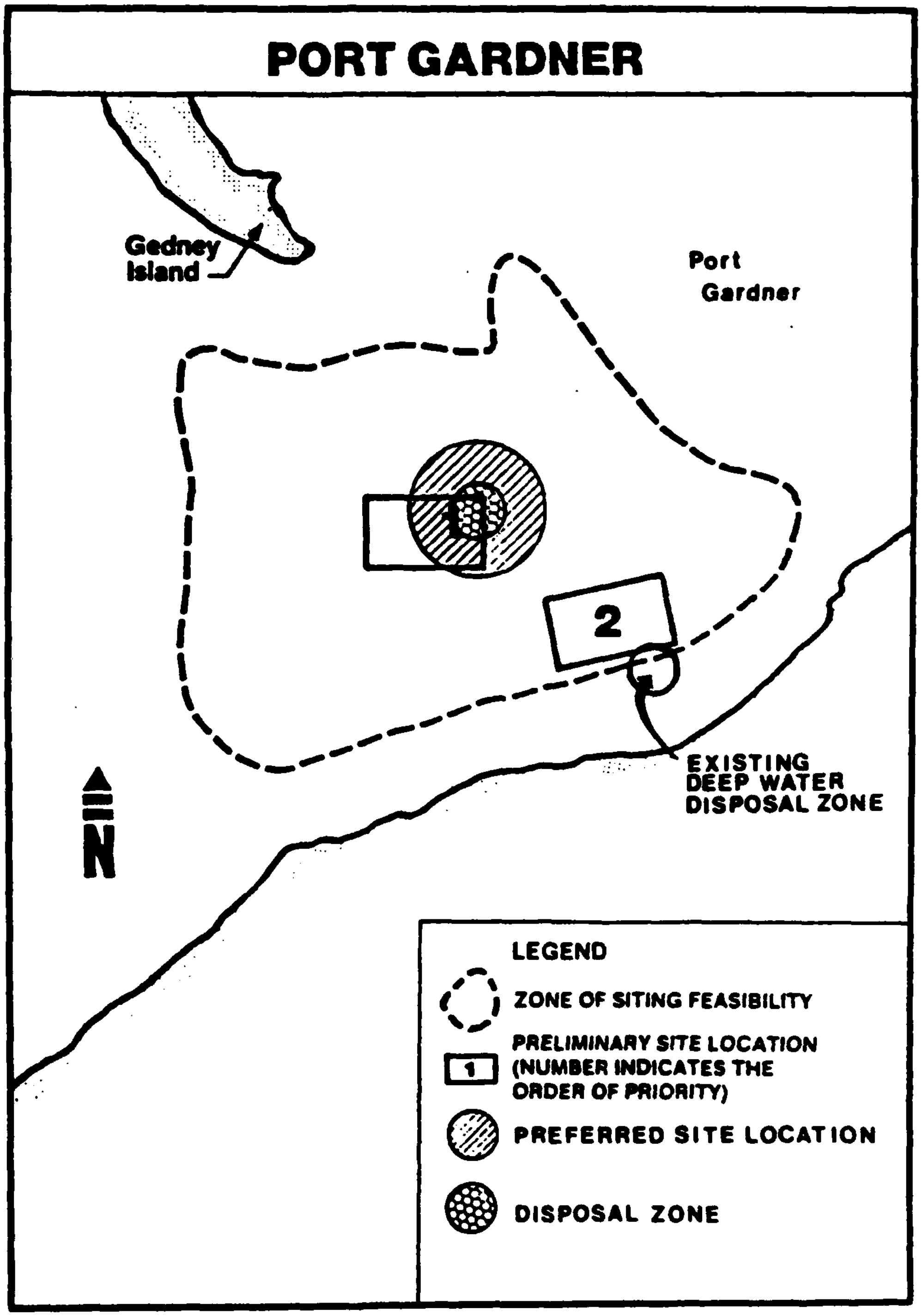


Figure II.3-2 Port Gardner ZSF with existing disposal site. (Source: Corps)

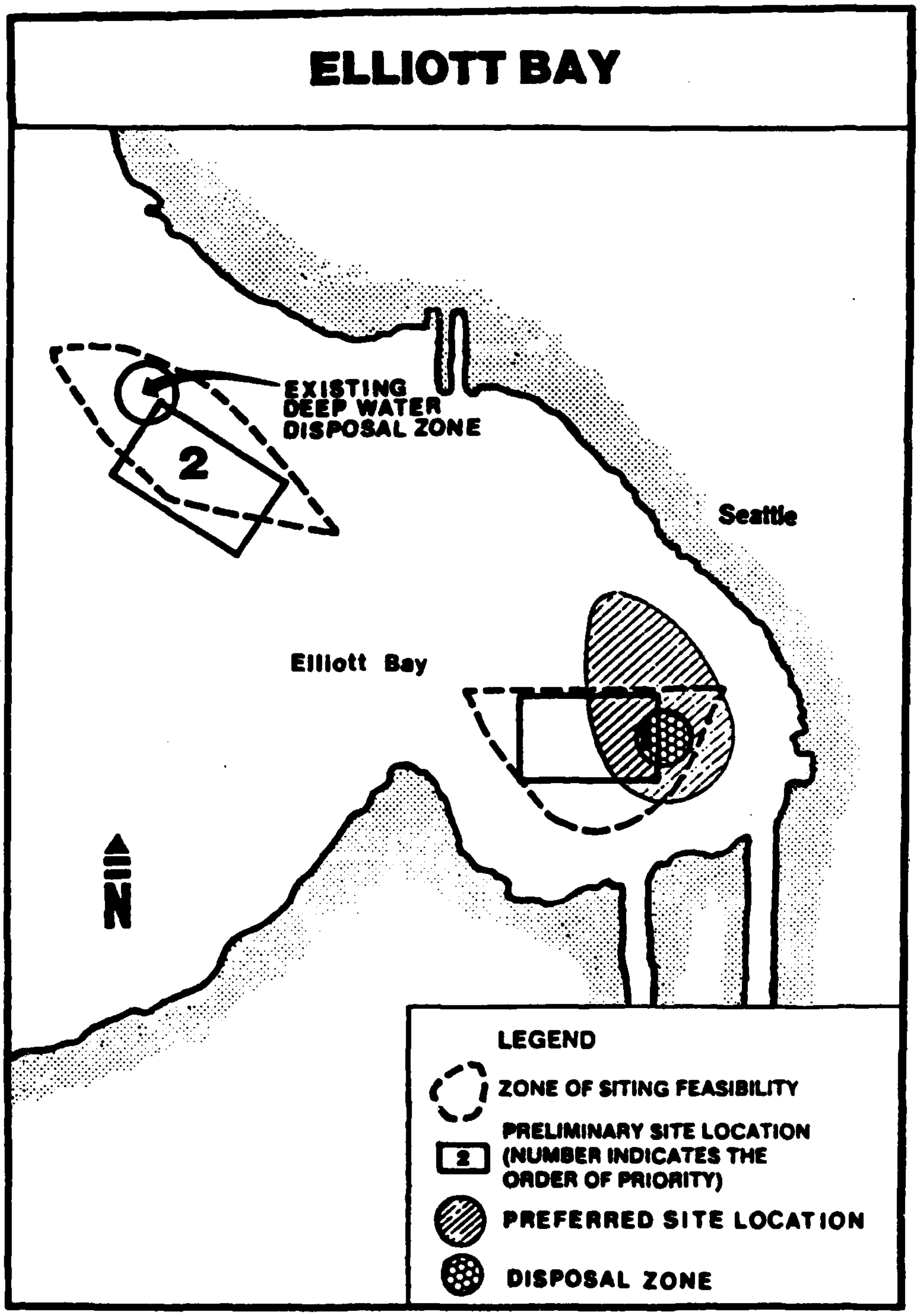


Figure II.3-3 Elliott Bay ZSF's with existing disposal site
(Source: Corps)

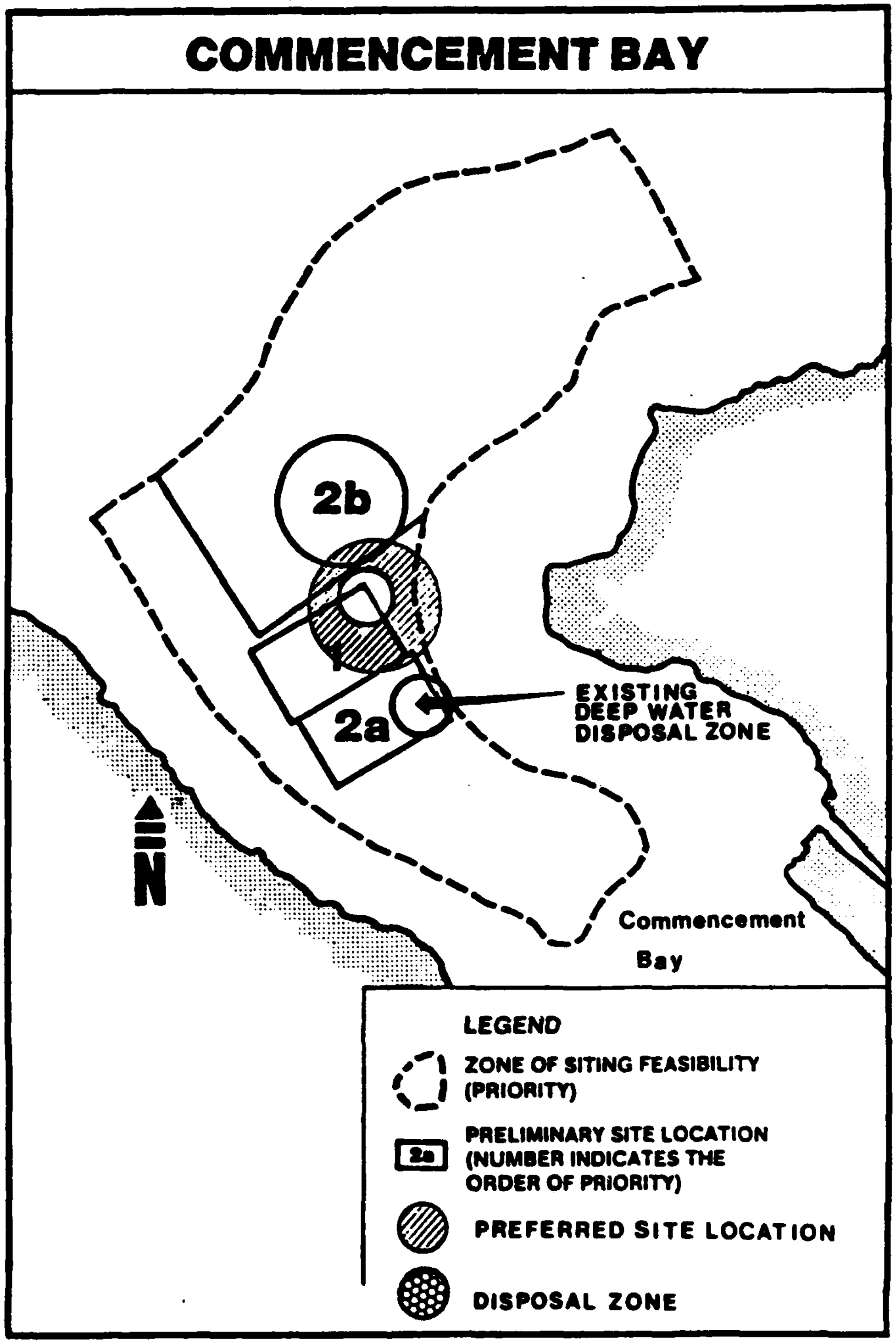


Figure II.3-4 Commencement Bay ZSF with existing disposal site. (Source: Corps)

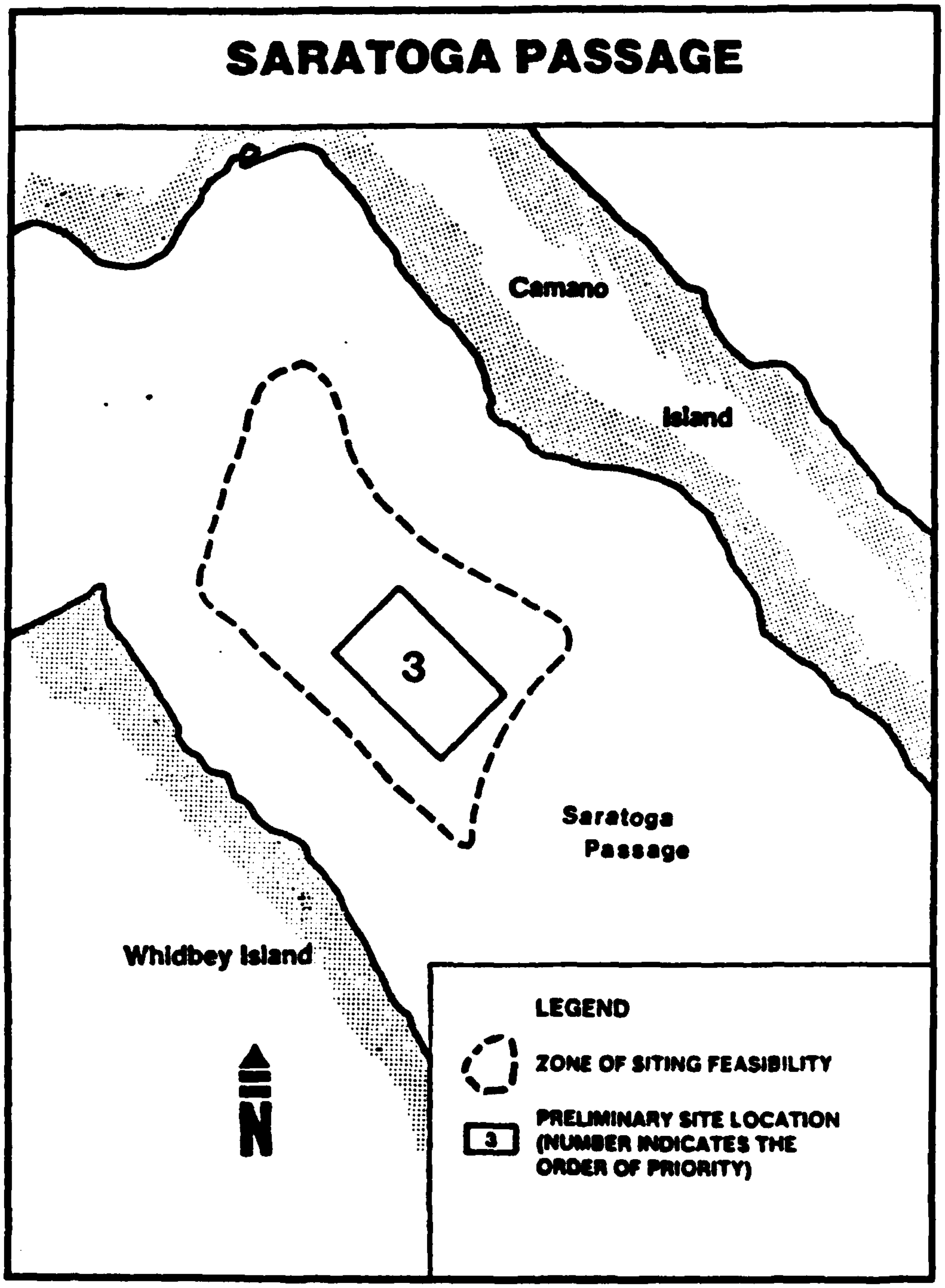


Figure II.3-5 Saratoga Passage ZSF. (Source: Corps)

4. BEGINNING THE SEARCH FOR DISPOSAL ZONES WITHIN THE ZSFs: SIZE ESTIMATES FROM THE NUMERICAL DREDGED MATERIAL DISPOSAL MODEL

To assist in establishing the appropriate size and location of a dredged material disposal zone within a ZSF, the numerical dredged material disposal model developed by the Corps Waterways Experiment Station (Trawle and Johnson, 1986) was used to estimate the depositional pattern caused by the disposal of a single barge load of dredged material of varying composition at selected depths and current speeds. These estimates, combined with an estimate of the target (drop) zone diameter, provided an initial assessment of the sediment pattern that might be caused by repeated disposal operations within a ZSF. The final size, orientation, and configuration of the disposal site were based on the results of the disposal model with those of depositional analysis, current characteristics, and bottom topography. The initial estimates of disposal zone size were also used to determine the regional sampling plans for mapping biological resources.

4.1 Characteristics of Dredged Material

The numerical dredged material disposal model requires as input the characteristics of the material to be dredged. As a guide to the characteristics of future dredging activities, sediment records from past dredging work were reviewed.

The available Corps records indicate the various types of sediment that have been previously dredged. The following records were reviewed: for the Port Gardner ZSF, five samples taken from Everett Harbor (Corps records designated NPDEN-GS-L, 74-S-59Q); for the Elliott Bay ZSF, 34 samples taken in the Duwamish Waterway (Sin-Lam Chan, et al., 1986); and for the Commencement Bay ZSF, six samples taken from the Hylebos Waterway (COE records designated NPDEN-GS-L, 78-S-4). Table II.4-1 lists the percentages of nine sediment types according to the Wentworth size classification. Shown are both the range of the percentages as well as the mean percentage for the samples taken in each area. The percentage ranges indicate great variability. Consider, for instance, that the percentage of medium sand varies between 4-63.5% in Everett Harbor, 2-44.6% in the Duwamish Waterway, and 1-30.5% in Hylebos Waterway. The ranges for medium silt and clay percentages vary between 0-28% in Everett Harbor, 3.1-76.5% in Duwamish Waterway, and 19.0-73.0% in Hylebos Waterway.

Despite the great variability, the mean values suggest that there are some differences between materials that will be deposited in the ZSFs. In Everett Harbor the most common sediment type is medium sand (37.2%); whereas in the Duwamish and Hylebos Waterways it is medium silt and clay (37.9% and

43.3%, respectively). It appears that future disposal operations will deal with a wide range of sediment types. If these past records are a guide then sand will be primarily deposited in Port Gardner, and finer sediments will be deposited in Elliott and Commencement Bays.

4.2 Numerical Dredged Material Disposal Model

4.2.1 Objective--

The objective of the dredged material disposal modeling effort was to predict the short term fate of material which may be dredged and disposed of in the Phase I area. The potential open water sites within the Priority 1 ZSFs are located in water depths ranging from 200 to 600 feet. A preliminary scan of the data base showed that tidal currents range from still water to speeds as great as two knots (3.4 feet per second) in the ZSFs (Priority 1 and 2).

4.2.2 Approach--

The numerical dredged material disposal model known as DIFID (Disposal from an Instantaneous Dump; Trawle and Johnson, 1986) was used to simulate the barge disposal of dredged material. The model predicted the pattern of disposed material on the bottom for each of a number of test conditions.

4.2.3 Description of the Numerical Model, DIFID--

DIFID was developed by Brandsma and Divoky (1976) for the COE Waterways Experiment Station under the Dredged Material Research Program. The original basis for the model was provided during earlier development by Koh and Chang (1973) for the EPA. Modifications to the original model have been made by Johnson and Holliday (1978) and Johnson (in preparation). Calibrations by Johnson and Holliday (1978) utilizing data collected by Bokuniewicz et al. (1978) have been conducted for disposal operations at the ZSF in inner Elliott Bay. The calibration results were used to select model coefficients within DIFID.

EPA is currently conducting a state-of-the-art review of available models for evaluating the initial mixing of wastes discharged in the ocean environment. This review had determined that the Koh-Chang model was the only model which accounted for configuration and movement of the disposal vessel (wake turbulence), and strongly suggests that the Koh-Chang model is certainly a valid model if not the most valid model currently available for these disposal evaluations.

The model requires that the dredged material be broken into various solid fractions with a settling velocity specified for each fraction. In many cases, a significant portion of the material falls as clumps that may have a settling velocity of one to five feet per second. This is especially true in Puget Sound, where much of the dredging is done by clamshell, and it can be true in the case of hydraulically dredged material if consolidation takes place in the hopper barge during transit to the disposal site. However, to determine the maximum extent of dispersion from a disposal operation, all of the model tests assumed that the dredged material was a slurry of uniform density.

The behavior of the disposed material was assumed to be separated into three phases: 1) convective descent, during which the discharge falls under the influence of gravity; 2) dynamic collapse, occurring when the descending material impacts the bottom; and 3) long-term passive dispersion, commencing when the material transport and spreading area are determined more by ambient currents and turbulence than by the dynamics of the disposal operation. Figure II.4-1 illustrates these phases.

During convective descent, the dumped material falls as a unit and it's volume grows by entrainment of surrounding water. Individual particle settling rate is not a factor during convective descent. The vertical motion is arrested and a dynamic spreading or collapse in the horizontal direction occurs when the material either reaches the bottom or a neutrally buoyant position in the water column. In 100 feet of water, the convective descent phase for typical maintenance dredged material is completed in a few seconds, and in 800 feet the convective descent lasts about two minutes.

The model assumes that none of the dredged material is lost to the surrounding water during the descent to the bottom. Later in this appendix it will be shown that several percent of the disposal material may remain suspended in the water column for a period of time. However, the model was not sufficiently sensitive to account for this small loss. This small effect was judged not to affect the dimensions of the lateral spread of dredged material on the bottom.

The model assumes that the collapsing cloud in the water column is an oblate spheroid. During collapse on the bottom, the cloud takes the shape of a general ellipsoid, and a frictional force between the bottom and the collapsing cloud is included. When the rate of horizontal spreading or vertical collapse in the dynamic collapse phase becomes less than an estimated rate of change due to turbulent diffusion, the collapse phase is terminated, and the long-term transport-diffusion begins. During collapse, solid particles settle at their specified settling rate. As these particles leave the main body of material, they are stored in small clouds that are assumed to have a Gaussian (or normal) distribution. The small

clouds are then advected horizontally by the model imposed current field. In addition, the clouds grow both horizontally and vertically as a result of turbulent diffusion. Since settling of the suspended solids occurs at each grid point, the amount of solid material deposited on the bottom and a corresponding thickness are determined.

4.2.4 Required Input Data--

The input data required for DIFID falls into four groups: (1) a description of the ambient environment at the disposal site; (2) characterization of the dredged material; (3) data describing the disposal operation; and (4) model coefficients.

The first task was that of constructing a horizontal grid over the disposal site. The model grid used for PSDDA is shown in Figure II.4-2. The ambient conditions imposed on the grid model for these tests were represented by a constant water depth, a constant current velocity, and a single water density profile.

The dredged material for these tests was characterized by two solid fractions. For each solid fraction the following information was specified based on Corps experience in Puget Sound: concentration by volume; density; fall velocity; voids ratio; and an indicator as to whether or not the fraction was cohesive. In addition, the bulk density and aggregate voids ratio of the material were prescribed. The bulk density is the density of the slurry in the barge. The aggregate voids ratio is a bulking factor used to convert the mass of deposited material into a thickness of deposition.

Disposal operations data required for DIFID included the position of the barge, the volume of dumped material, and the loaded and unloaded draft of the disposal vessel.

There are fourteen model coefficients in DIFID. These coefficients pertain to entrainment, drag, and turbulent dispersion. Computer experimentation has shown that the results are insensitive to many of the coefficients (Johnson and Holliday, 1978). The most important coefficients are drag coefficients in the convective descent and collapse phases as well as coefficients governing the entrainment of ambient water into the dredged material cloud. The values selected for the convective descent entrainment and drag coefficients in this study were based upon experimental work done for the EPA by Bowers and Goldenblatt (1978). A detailed description of the theoretical aspects of DIFID is given by Brandsma and Divoky (1976).

4.2.5 Test Conditions--

The test conditions included water depth, ambient current, material dumped, and barge bulk density. The conditions used in each of the tests are shown in Table II.4-2. The remainder of the required model input for each series is shown in Table II.4-3. See Trawle and Johnson (1986) for a description of the model coefficients used in this study. The model grid used for all tests is shown in Figure II.4-2, which represented an area within a square boundary measuring 12,000 by 12,000 feet. Each grid cell represented an area of 400 by 400 feet. To be representative of a typical disposal operation in Puget Sound, the volume used in all simulations was 1,500 cubic yards.

The duration of each test simulation generally lasted one hour after the barge dump. In the tests with high ambient current speeds (3.38 feet per second), dumped material remained in suspension and reached the 12,000 foot boundaries within one hour thereby automatically ending the simulation.

The deposition of material predicted by the model is converted to thickness of deposition by the use of an aggregate voids ratio. The conversion from solids volume deposited to thickness of deposition is that of Brandsma and Divoky (1976).

The dumping of two types of material was simulated by the model in these tests. These were chosen to represent the most dispersive materials dumped into Puget Sound. The primary material tested consisted of 25 percent fine sand and 75 percent clay/silt. The clay/silt fraction was modeled both as cohesive and noncohesive material. The second material consisted of 50 percent fine sand and 50 percent medium sand with no clay/silt.

4.2.6 Test Results

Results from the model tests are shown as deposition patterns in Figures II.4-3 - II.4-7b. These deposition patterns show the predicted extent and thickness of material deposited from a single disposal operation.

The material simulated in Tests 1-15 represents a typical maintenance material in Puget Sound consisting of 25 percent fine sand and 75 percent clay/silt. In these tests, the clay/silt fraction was treated as a cohesive material and allowed to aggregate thus yielding settling rates which are significantly greater than the individual particle settling rate. For fine-grained silts and clays, it is reasonable to assume that particle aggregation will occur as the material settles, resulting in accelerated settling rate. The aggregate settling rate for the clay/silt fraction is determined in the model by the equations of Johnson and Holliday (1978).

For Tests 1 through 12, in depths of water ranging from 100 to 600 feet, all of the dumped material deposited within sixty minutes. For Test 13, in 800 feet of water and with an ambient current speed of 0.1 feet per second, all of the material deposited within one hour; however, for Test 14, in 800 feet of water and a current speed of 1.69 feet per second, a portion of the clay/silt fraction was still settling after one hour. For Test 15, in 800 feet of water and a current speed of 3.38 feet per second, the duration of the simulation was limited to 30 minutes at which time a portion of the clay/silt fraction was still descending downward.

Tests 16-18 were identical to Tests 7-9 except that the clay/silt fraction was not allowed to aggregate; therefore, only particle settling velocities were used in the model computations. Comparison of Tests 7-9 to Tests 16-18 demonstrates that the deposition pattern is much more dispersed if aggregate settling is not considered. However, tests 16-18 are not considered to be representative of anticipated dredge material (i.e., the material will aggregate).

Test 19 is identical to Test 18 except that the barge bulk density was increased from 1.35 to 1.48. The impact of the increased bulk density with regard to the extent of the deposition pattern was negligible under these conditions.

Test 20 used a material which consisted only of fine and medium sands dumped in water 800 feet deep with an ambient current of 1.69 feet per second. Test 21 was identical to Test 20 except that the water depth was 100 feet.

4.3 Preliminary Disposal Site Dimensions

The existing disposal sites shown on various NOAA charts are circular areas measuring 1800 feet in diameter. This area circumscribes the DNR prescribed "disposal zone" for a disposal barge, or the area within which the dredged material should be released at the water surface. To evaluate the impact of dredged material on bottom dwelling animals, it was necessary to define a larger zone within which the material would be deposited, based on a series of dumps, as shown by the results from the numerical dredged material disposal model. To plan the PSDDA field studies, preliminary dimensions were chosen. It was later modified as a result of the field studies. The final disposal zones are described later in this technical appendix.

The PSDDA disposal site consists of three zones labeled A, B, and C (Fig. II.4-8). Area A is the target area, and Area B is the disposal zone. The disposal barges should open their hoppers within A, but allowing for some error, within an area no larger than B. The target area A and disposal zone B lie within Area C, defined as the disposal site. The rectangle circum-

scribes the horizontal spread over a period of repeated dumps of the dredged material after it is released at different locations within the disposal zone during both flood and ebb tides (assuming a current speed of 0.5 knot or 0.85 feet per second).

The dynamics of individual disposal operations were described earlier using the numerical dredged material disposal model. The dimensions of the dump site were chosen using results corresponding to typical water depths and currents envisioned for the disposal sites. The choice was based on model Test No. 8 for 400 feet water depth and a 0.5 knot current (0.85 feet per second) (Fig. II.4-5a). This test indicated a horizontal spread of approximately 1000 feet downstream from the dump spot and 600 feet to either side. As a precaution 600 feet and 1000 feet were added to the short and long (tidal current direction) axes dimensions, respectively, to arrive at the size (3000 by 3800 feet) of the rectangle shown in Figure II.4-8.

Table II.4.1 PERCENTAGES OF SEDIMENT TYPES IN SEDIMENTS FROM EVERETT HARBOR, DUWAMISH WATERWAY, AND HYLEBOS WATERWAY.

Sediment Type	(1) Everett Harbor (5 samples) Range	(mean)	(2) Duwamish Waterway (34 samples) Range	(mean)	(3) Hylebos Waterway (6 samples) Range	(mean)
Gravel						
Sand	0-11.0	(3.3)	0.2-8.0	(3.2)	0-3.0	(0.5)
Very coarse	0-16.0	(7.5)	0.3-4.1	(1.9)	0-3.0	(0.8)
Coarse	1.0-38.0	(25.2)	0.3-14.0	(4.9)	0-11.0	(3.6)
Medium	4.0-63.5	(37.2)	2.0-44.6	(19.7)	1.0-30.5	(10.8)
Fine	6.0-21.0	(11.1)	4.1-35.9	(16.6)	4.0-34.0	(16.4)
Very fine	0.5-32.5	(7.4)	4.0-22.1	(12.2)	6.5-22.0	(13.5)
Coarse silt	0-13.5	(2.7)	1.5-15.6	(4.9)	5.0-14.0	(11.2)
Medium silt-clay	0-28.0	(5.6)	3.1-76.5	(37.9)	19.0-73.0	(43.3)

Sources: (1) COE Seattle District records designated NPDEN-GS-L, 74-S-590.

(2) Sin-Lam Chan et al., 1986.

(3) COE Seattle District records designated NPDEN-GS-L, 78-S-4.

TABLE II.4-2 CONDITIONS USED IN THE 21 TEST RUNS OF THE NUMERICAL DREDGED MATERIAL DISPOSAL MODEL.

Test No.	Water Depth (feet)	Current speed (fps)	Time (min)	Material Fine Sand %	Type Clay/Silt %	Cohesive Y/N	Deposited Fine Sand %	Clay/Silt %
1	100	0.10	60	25	75	Y	100	100
2	100	1.69	60	25	75	Y	100	100
20	100	1.69	60	100	0	N	100	0
3	100	3.38	60	25	75	Y	100	100
4	200	0.10	60	25	75	Y	100	100
5	200	0.85	60	25	75	Y	100	100
6	200	1.69	60	25	75	Y	100	100
7	400	0.10	60	25	75	Y	100	100
16	400	0.10	60	25	75	N	100	53
8	400	0.85	60	25	75	Y	100	100
17	400	0.85	60	25	75	N	100	18
9	400	1.69	60	25	75	Y	100	100
18	400	1.69	60	25	75	N	100	14
19	400	1.69	60	25	75	N	100	15
10	600	0.10	60	25	75	Y	100	100
11	600	0.85	60	25	75	Y	100	100
12	600	1.69	60	25	75	Y	100	100
13	800	0.10	60	25	75	Y	100	93
14	800	1.69	60	25	75	Y	93	67
21	800	1.69	60	100	0	N	100	0
15	800	3.38	30	25	75	Y	66	55

TABLE 4.3 ADDITIONAL MODEL INPUT INFORMATION USED IN THE 21 TEST RUNS OF THE NUMERICAL DREDGED DISPOSAL MODEL.

	Tests 1-15	Tests 16-18	Test 19	Test 20-21
Medium sand concentration by volume (cu ft/cu ft)	--	--	--	0.15
Fine sand concentration by volume (cu ft/cu ft)	0.05	0.05	0.07	0.15
Clay-silt concentration by volume (cu/ft/cu ft)	0.16	0.16	0.22	--
Sand density (gm/cc)	2.60	2.60	2.60	2.60
Silt-clay density (gm/cc)	2.60	2.60	2.60	--
Fluid density (gm/cc)	1.018	1.018	1.018	1.018
Medium sand fall velocity (fps)	--	--	--	0.03
Fine sand fall velocity (fps)	0.02	0.02	0.02	0.02
Clay-silt fall velocity (fps)	0.0013	0.0013	0.0013	--
Dredged material bulk density (gm/cc)	1.35	1.35	1.48	1.48
Aggregate voids ratio	4.50	4.50	4.50	4.50
Cohesive Aggregate Option for clay/silt fration	On	Off	Off	Not Applicable

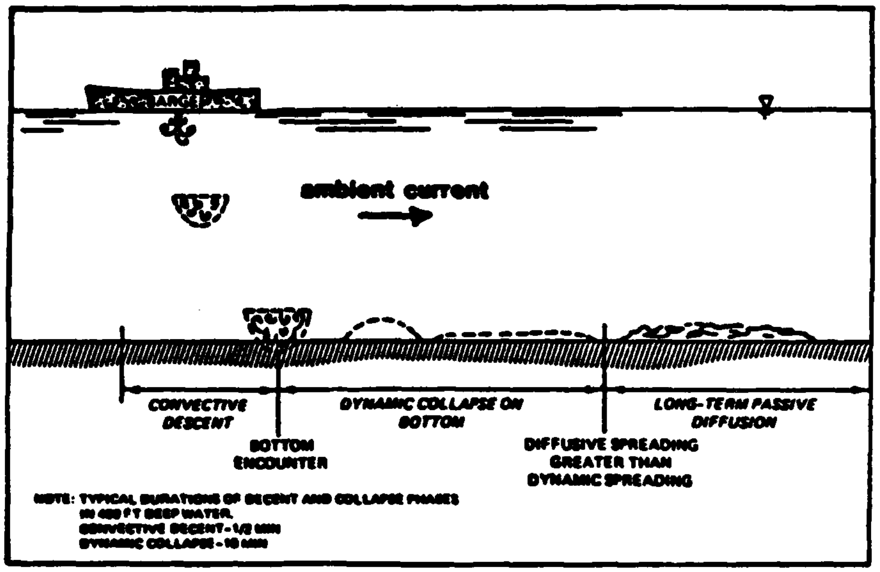


Figure II.4-1 Conceptual diagram of the disposal of dredged material used in the numerical dredged material disposal model. (Source: Trawle and Johnson, 1986)

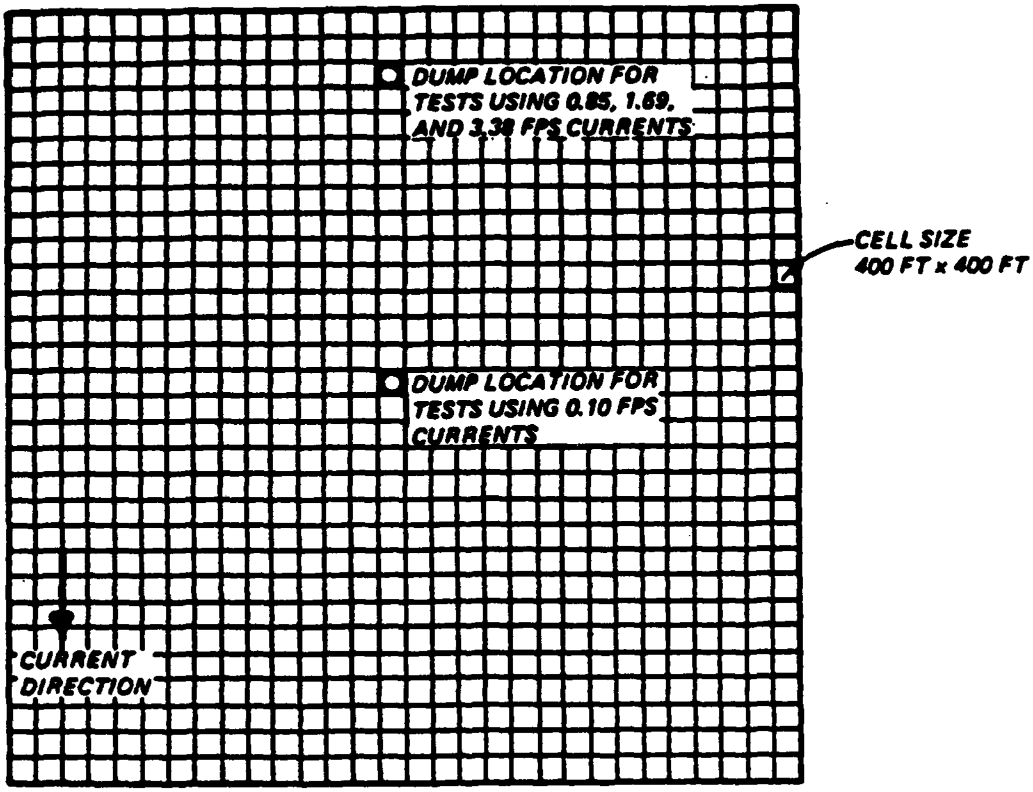


Figure II.4-2 Horizontal grid used in the numerical dredged material disposal model. (Source: Trawle and Johnson, 1986)

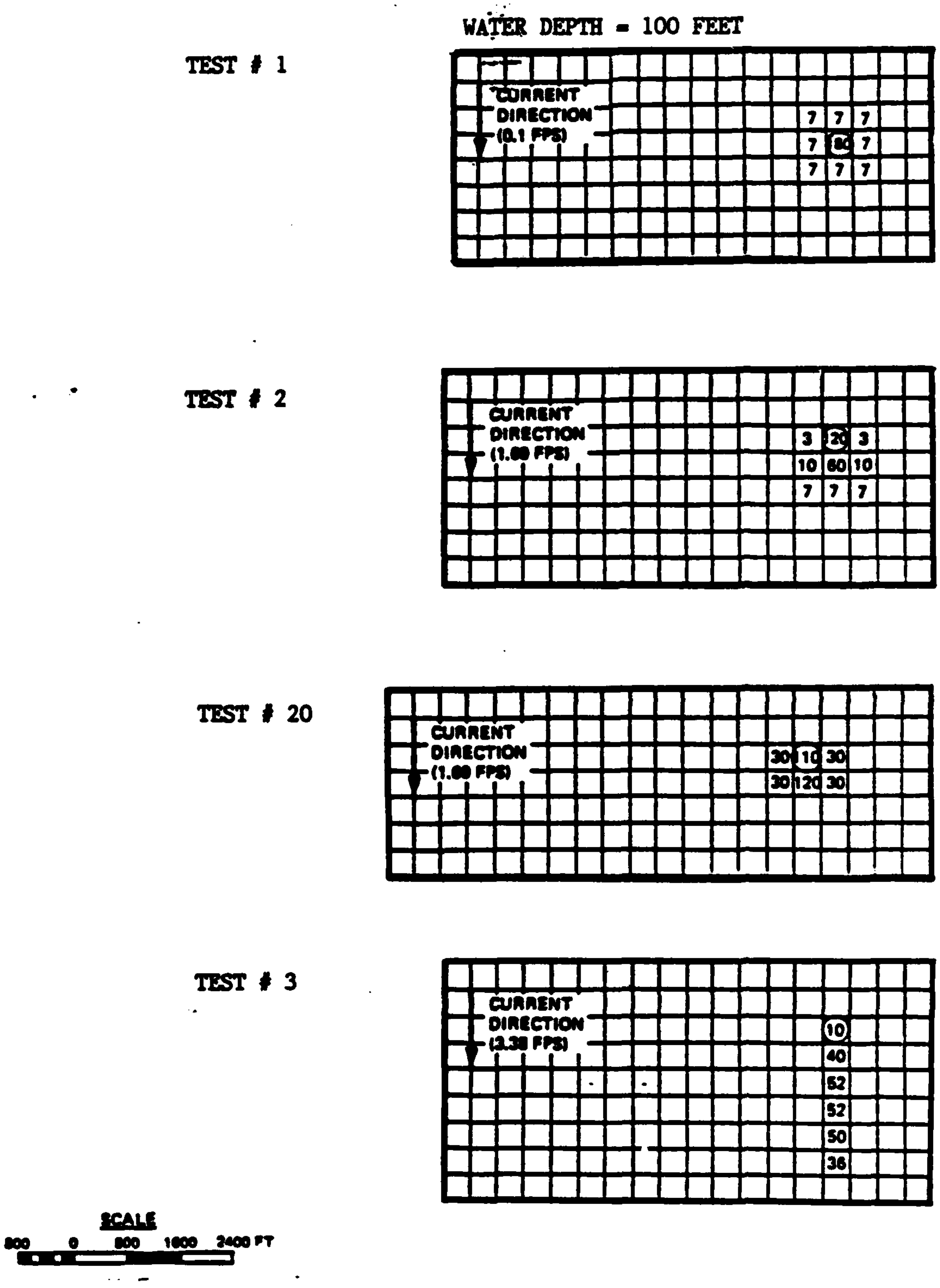


Figure II.4-3 Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 100 feet of water and various current speeds. Circle indicates dump zone. (Source: Trawle and Johnson, 1986)

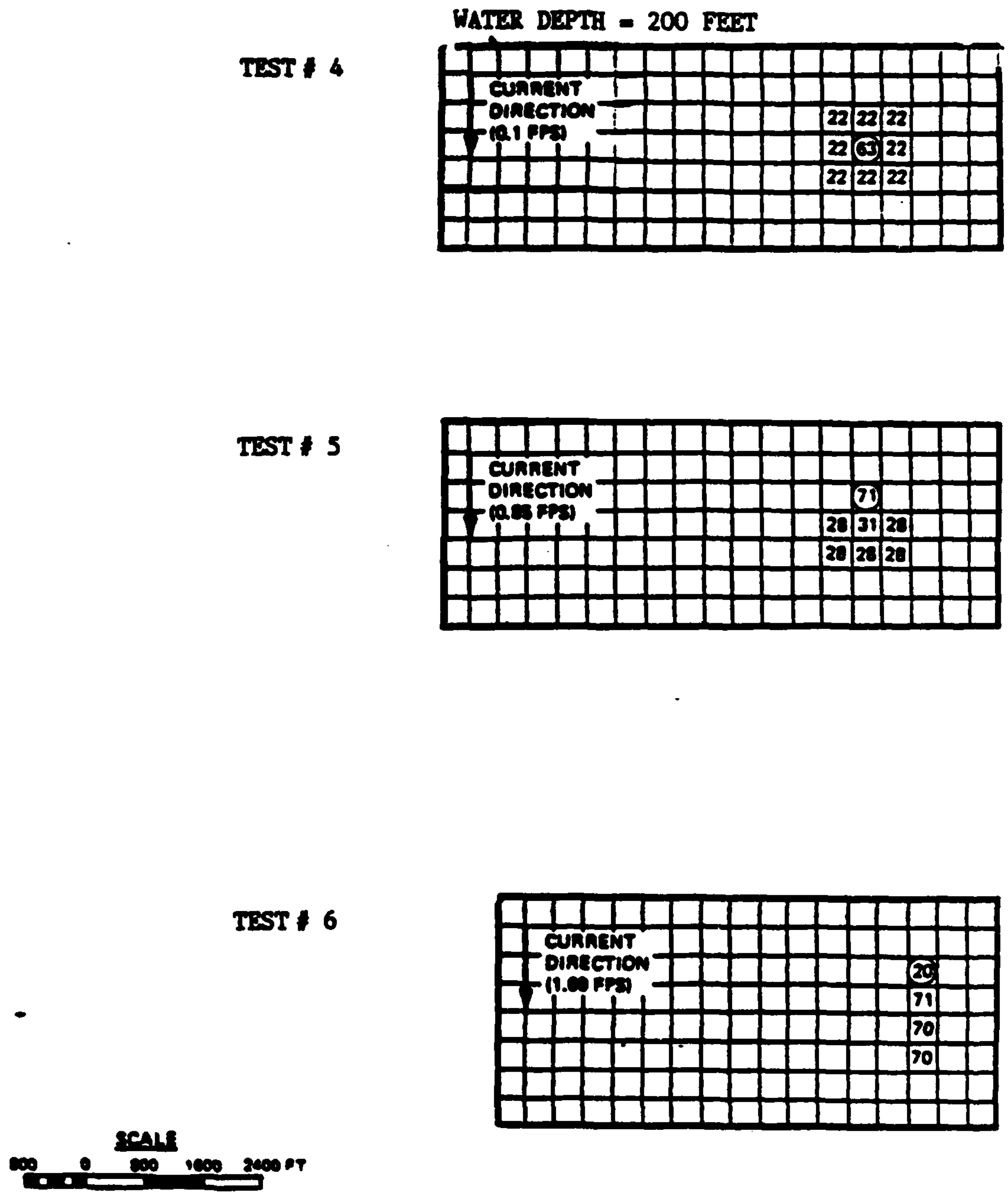


Figure II.4-4 Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 200 feet of water for various current speeds. Circle indicates dump zone. (Source: Trawle and Johnson, 1986).

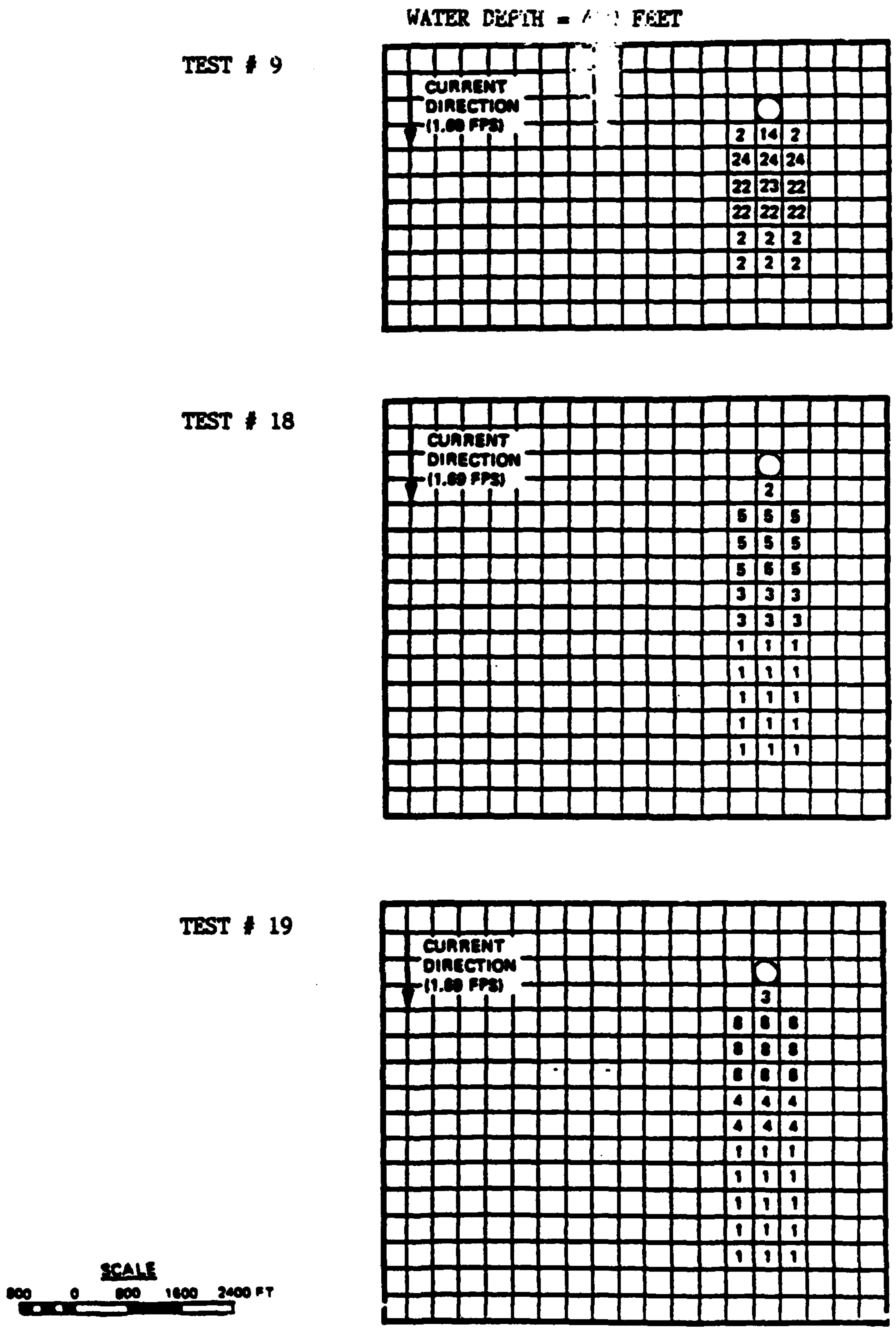


Figure II.4-5a Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 400 feet of water for various current speeds. Circle indicates dump zone. (Source: Trawle and Johnson, 1986)

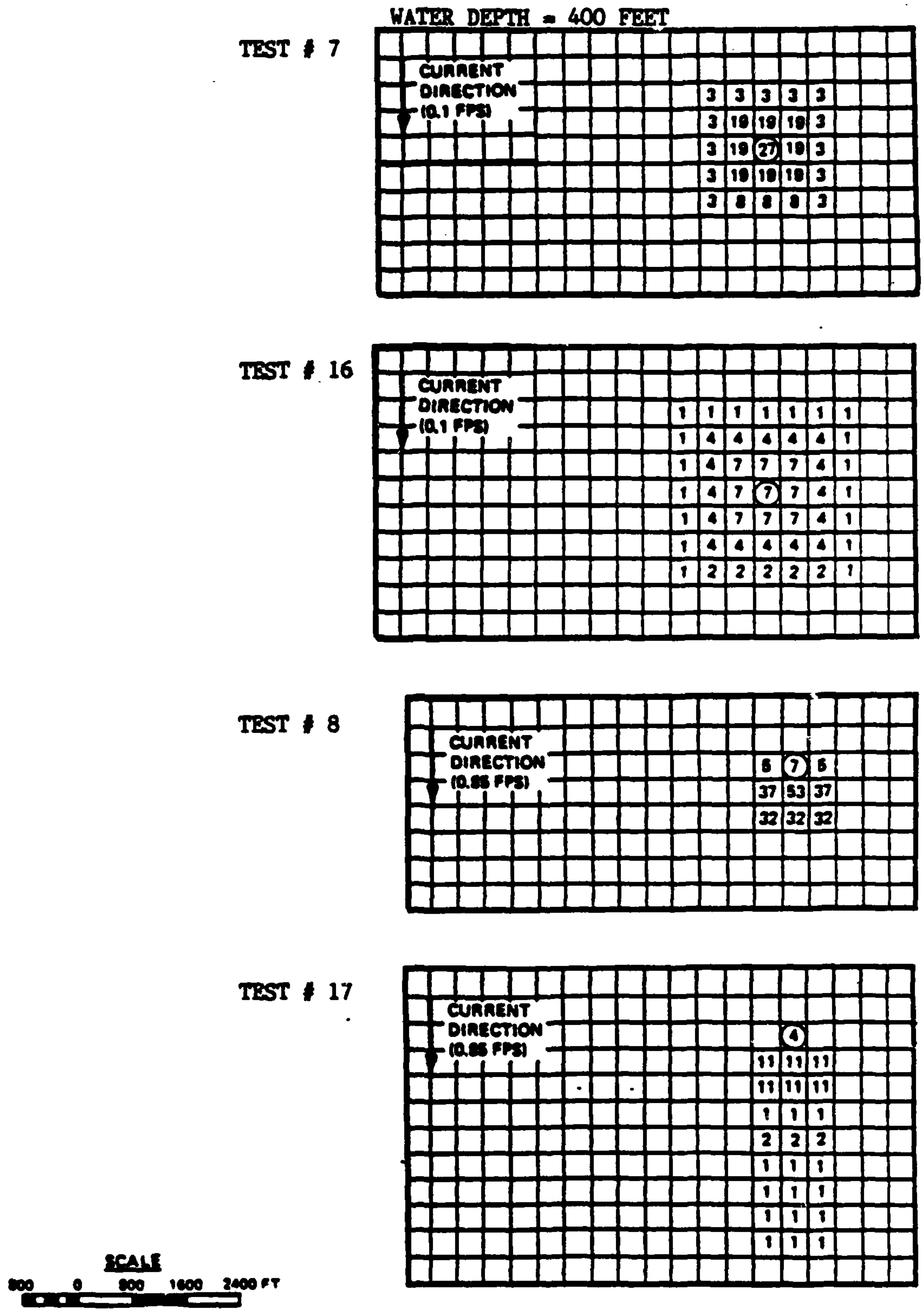


Figure II.4-5b Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 400 feet of water for various current speeds. Circle indicates dump zone. (Source: Trawle and Johnson, 1986)

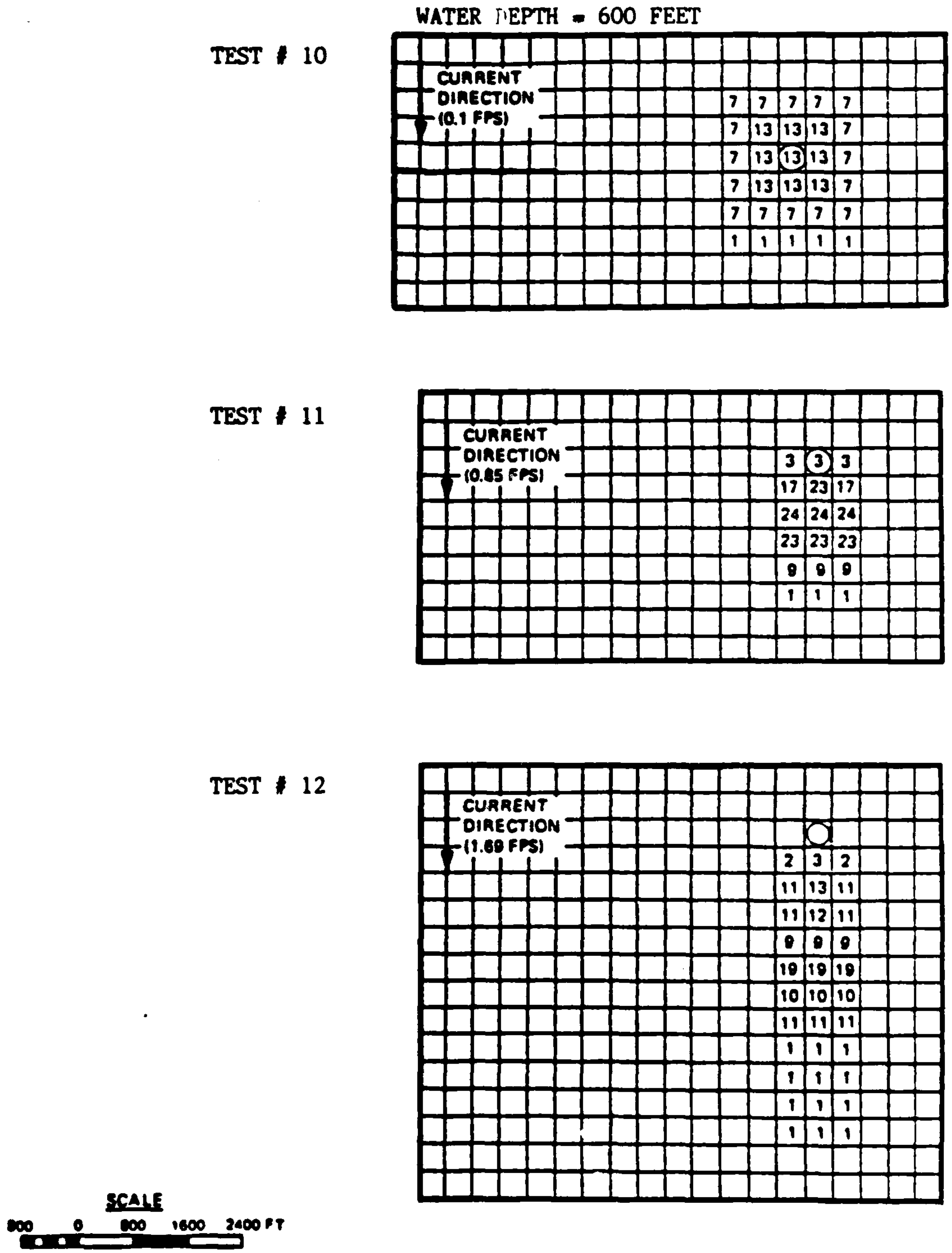


Figure II.4-6 Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 600 feet of water for various current speeds. Circle indicates dump zone. (Source: Trawle and Johnson, 1986)

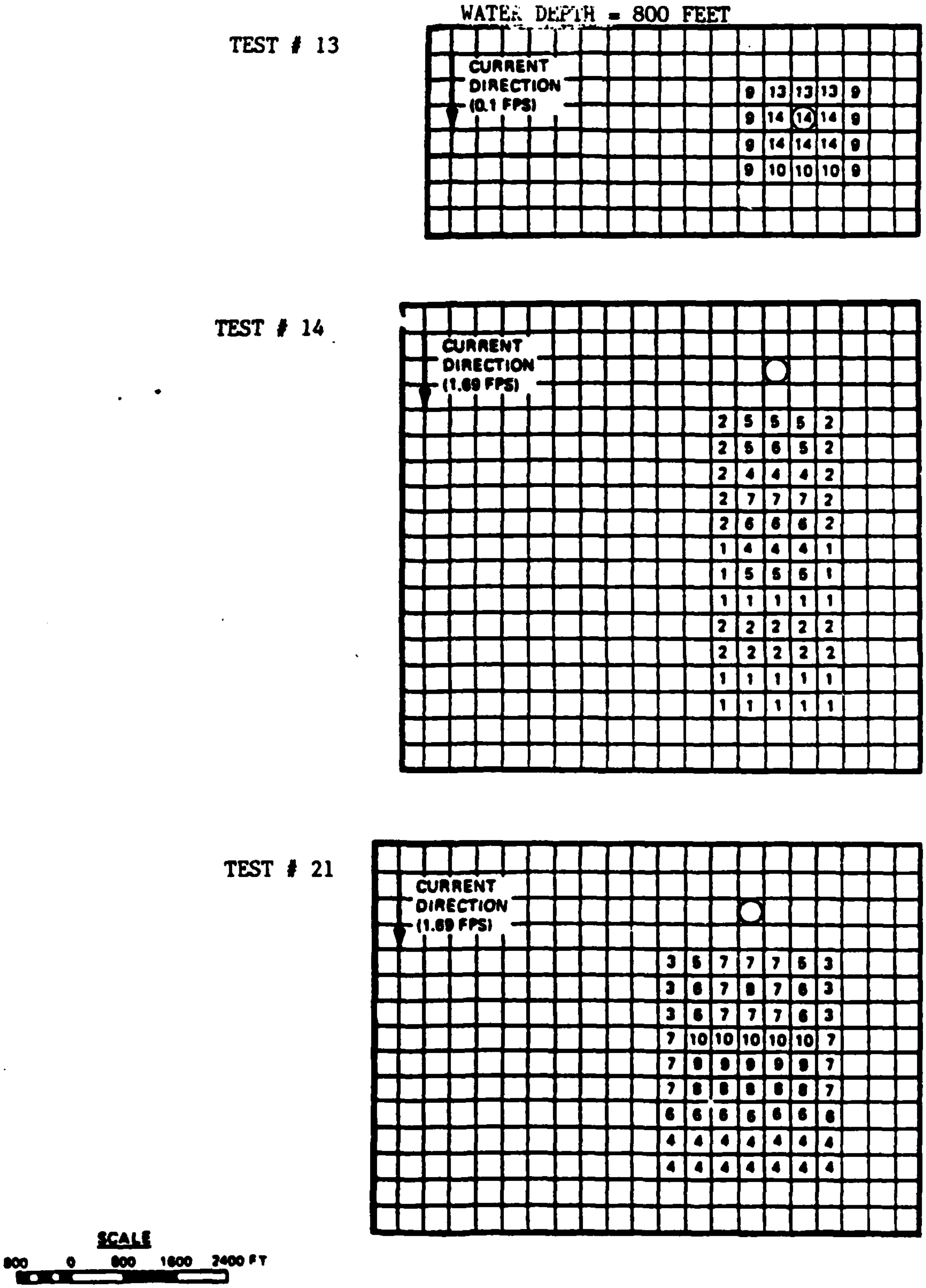
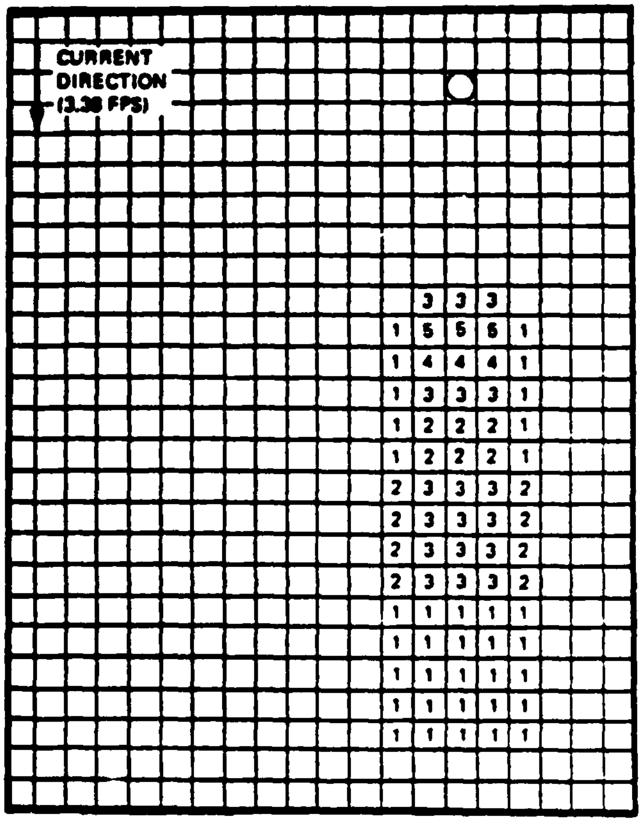


Figure II.4-7a Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 800 feet of water for various current speeds. Circle indicates dump zone. (Source: Trawle and Johnson, 1986)

WATER DEPTH = 800 FEET

TEST # 15



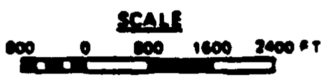


Figure II.4-7b Deposition pattern (in thousandths of a foot) from the numerical dredged material disposal model in 800 feet of water for various current speeds. Circle indicates dump zone. (Source Trawle and Johnson, 1986)

PRELIMINARY DISPOSAL SITE DIMENSIONS

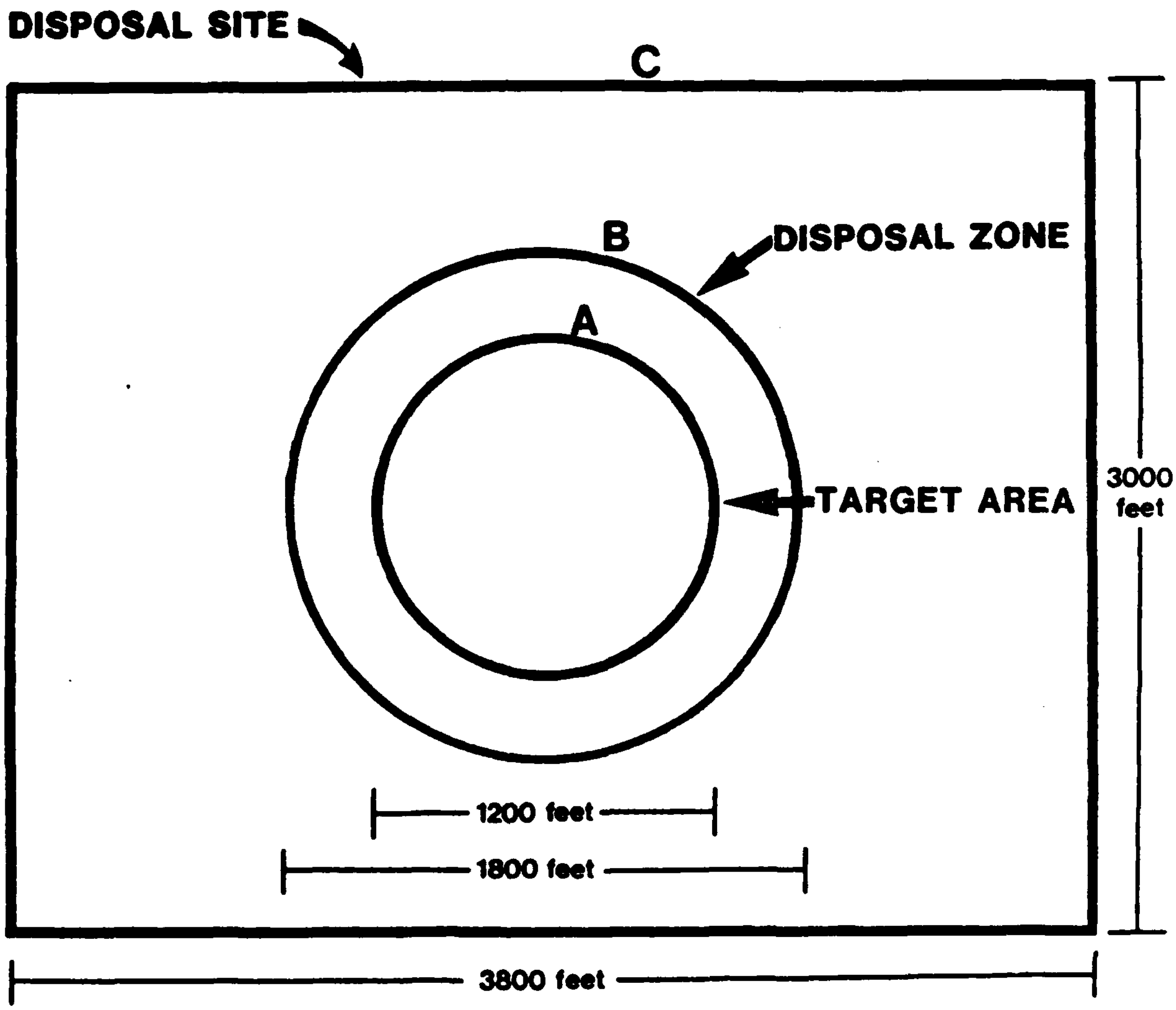


Figure II.4-8 Preliminary dimensions of the PSDDA disposal site. (Source: EHI)

5. DEPOSITONAL ANALYSIS/SEDIMENT CHARACTERIZATION

5.1 Objective

The objective was to locate areas within the ZSFs where sediments tend to deposit rather than erode, and areas that were large enough to encompass preliminary disposal sites. These determinations were made from maps of sediment characteristics.

5.2 Background

Previous work by Word et al. (1984a) indicated that sediments in Puget Sound tend to accumulate where existing sediments meet four criteria when compared to sediments at similar depths: 1) small grain size; 2) statistically elevated volatile solids; 3) statistically elevated biochemical oxygen demand; and 4) statistically elevated water content. During PSDDA field studies, measurements were made in the ZSFs to evaluate these criteria.

5.3 Depositional Analysis Technique

The assessment of depositional potential was determined from characteristics of the sediments in the ZSFs. The analysis presented below was adapted from Striplin et al. (1987).

The depositional analysis was conducted within the five ZSFs. The ZSFs were sampled with 201 stations as follows: 1) Saratoga Passage, 24 stations on 24 April; 2) Port Gardner, 72 stations on 10, 11, 14 April; 3) Elliott Bay, 34 stations on 9, 10 April; and 4) Commencement Bay, 61 stations on 7, 8 April, 1986.

Subtidal sediment samples were collected in a consistent, repeatable manner with a 0.1 square meter modified van Veen grab sampling device. Upon collection of each sample, the following physical characteristics of the sediment were described and recorded: sediment texture and color; strength and type of odors; sampler penetration depth; degree of leakage or sediment surface disturbance; and obvious abnormalities, e.g., wood debris and biological structures. Samples which showed excessive disturbance of the sediment surface were rejected. In addition, sediment samples were rejected if they did not meet certain minimum penetration depths. Samples were taken from the upper two centimeters of the sediments.

Sediments larger than 62 microns were air dried and analyzed by dry sieving through a series of graded sieves using a Braun mechanical shaker. Sediments finer than 62 microns were

analyzed by wet pipetting techniques. Sediments were then classified into the following size categories: cobble (156-64 millimeters), gravel (64-2 millimeters), coarse sand (2-0.5 millimeters), fine sand (0.5-0.062 millimeters), silt (0.062-0.004 millimeters), and clay (less than 0.004 millimeters). Percent volatile solids (%VS) were determined by combustion at 550oC, once the samples were completely thawed and homogenized. The 5-day biochemical oxygen demand (BOD; milligrams of oxygen used per kilogram of sediment, dry weight) was determined following procedures in Standard Methods for the Examination of Water and Wastewater (1985) and in the PSEP protocols manual, with some modifications (see Striplin et al., 1987). The percent water was determined by over drying a weighed aliquot of homogenized sediment, and weighed again for computation of percent water.

The grain size numbers which are contoured are arbitrary numbers which represent the sediment types shown in the legend of each grain size map (Striplin et al., 1987). These numbers are not related to phi sizes in any way.

Sediment grain size in some of the ZSFs was also estimated using the REMOTS system (see Cooper Consultants, 1986). Although this method allows the recognition of grain sizes greater than or equal to coarse silt (5 phi size), the REMOTS data available to PSDDA were not resolved finer than very fine sand (4 phi size). As it turns out later, the depositional areas are characterized by fine silt and clay type sediments (7-9 phi size); therefore, the REMOTS technique did not provide sufficient resolution of small grain sizes to locate the depositional areas within the ZSFs.

A statistical method was employed to determine if individual samples indicated a station to be more depositonal in nature than other stations at a similar depth. The mean, standard deviation, 95% confidence interval (95% CI), and 1.96 standard normal deviate (1.96 SND) were calculated for each parameter for each depth contour using data from all 201 stations as described by Word et al. (1984a,b). Values falling beyond the 1.96 SND were considered outliers. They were temporarily removed from the data, and the computations performed again. Removal of the outliers decreased the variance and produced more realistic average values for the data. Once the final mean, 95% CI and 1.96 SND were obtained for each depth contour, the observed values (including outliers) were compared to the values at each depth.

The data from each region were examined to determine which areas exceeded the upper bounds for %VS, BOD, and water content. A range of +1.96 standard normal deviate was chosen for the upper bound in addition to the 95% confidence interval to identify those stations which departed subatantially from mean values.

A station was considered depositional if the percent volatile solids, BOD, or percent water exceeded the 95% confidence limit for the depth contour on which the station was located. In addition, the sediment grain size must have a mean size of 7 (fine silt), 8 (very fine silt), or 9 (clay).

The data obtained from the REMOTS system in some ZSFs was also used to estimate areas that were depositional or erosional (Cooper Consultants, 1986). The classification depended on the characteristics of the sediment-water interface (e.g., mud clasts and small scale bedforms). These features may have been associated with a local winter storm that occurred at the time of the REMOTS surveys; therefore, the erosional/deposition maps prepared from REMOTS data may represent a short term pattern.

In contrast to the REMOTS maps which represent the bedform patterns at the sediment surface, the maps prepared from conventional techniques were derived from the upper two centimeters of sediment. As sediments deposit naturally at the rate of 0.5 - 2 centimeters per year (Lavelle et al., 1986), the depth sampled by conventional methods represents approximately two years of accumulated sediment. DSWG relied on conventional sediment chemistry to locate depositional sites because it represented a longer period of sediment accumulation than did the REMOTS data.

5.4 Distribution in the ZSFs

5.4.1 Saratoga Passage--

In the Saratoga Passage ZSF, the percent volatile solids ranged from under 2% to over 8% (Fig. II.5-1). Elevations above the 95% CI were found at most of the stations within the ZSF, and four of the seven stations in the ZSF were elevated above the 1.96 SND interval (Fig. II.5-1).

The BOD values ranged from under 300 to over 1000 milligrams per kilogram of dry weight (Fig. II.5-2). The highest levels were found at the east and west ends of the ZSF. Values exceeded the 95% CI at the west end and at four stations within the ZSF (Fig. II.5-2).

Percent water values showed similar trends as those seen in the %VS and BOD (Fig. II.5-3). Elevations beyond the 95% CI were found in the central portion of the ZSF (Fig. II.5-3).

The median sediment grain size found in the ZSF was predominantly medium to fine silt (Fig. II.5-4). Stations along the margins of Camano and Whidbey Islands had sediments consisting of fine sand. The percent clay in the ZSF ranged from approximately 10% to over 15% (Fig. II.5-5).

5.4.2 Port Gardner--

In the Port Gardner ZSF, the percent volatile solids concentrations ranged from under 2% to over 8% (Fig. II.5-6). Elevations above the 95% CI were found at most of the stations in the ZSF (Fig. II.5-6). Five stations along the northeast margin of the ZSF and three stations near the entrance to the Everett Marina exceeded the 1.96 SND.

The BOD ranged from 200 north of Gedney Island to 1500 in Possession Sound (Fig. II.5-7). Values in excess of the 95% CI were found in the easternmost, central, and western portions of the ZSF (Fig. II.5-7). Stations where values exceeded the 1.96 SND were found at the entrance to Possession Sound and at two stations on the eastern margin of the ZSF.

The percent water ranged from approximately 40% to greater than 60% throughout most of the ZSF (Fig. II.5-8). The areas where the water content exceeded the 95% CI show a distribution similar to that seen for BOD with the elevations principally occurring in the easternmost, central and western margins of the ZSF (Fig. II.5-8).

The median sediment grain size found in most of the ZSF was medium and fine silt, and the percent clay ranged from 10-20% (Fig. II.5-9,10). Sediments along the south and east ends of the ZSF were coarser ranging from fine to very fine sand.

5.4.3 Elliott Bay--

The total volatile solids concentrations in the inner bay increased with increasing water depth and distance down the submarine canyon, off the west waterway of the Duwamish River (Fig. II.5-11). Low values near 1% were found immediately off the waterway, and values increased to 7% at the base of the canyon. Most stations in the inner bay showed enhancements in volatile solids greater than the 1.96 SND (Fig. II.5-11).

The range of volatile solids values at the Fourmile Rock ZSF was 1.6% to 7% (Fig. II.5-11). A tongue of sediment with low volatile solids extended from the northern inshore stations. None of the stations within this ZSF were elevated above the depositional criteria.

The BOD values at the inner bay ZSF ranged from 300 to over 700 milligrams per kilogram dry weight (Fig. II.5-12). Values increased with depth and down the submarine canyon. High values were also found along the eastern side of the bay. Elevations beyond the 95% CI were found in a horseshoe pattern, with two stations below the 95% CI. Values at Fourmile Rock ranged from less than 500 at inshore stations, to over 1000 at the deep

stations. As with volatile solids, a tongue of sediment with low BOD extended into the ZSF from the northern inshore stations (Fig. II.5-12). Five stations fell above the 95% CI for BOD.

Percent water values followed the patterns previously described for %VS and BOD (Fig. II.5-13). The data indicate that in the inner bay, percent water increased with depth from less than 40% at the mouth of the west waterway to over 60% at the base of the submarine canyon (Fig. II.5-13). All but one station had percent water values in excess of the 95% CI level. Values at the Fourmile Rock ZSF were similar to those in inner Elliott Bay, and ranged from less than 40%, to over 60%. The band of lower percentage water is broader than seen in the %VS and BOD measurements, but it is still distinct.

The median grain size ranged from coarse sand, located at the station closest to the west waterway in inner bay, to coarse silt as depth increased (Fig. II.5-14). The percent clay in most of the inner bay ZSF was from 9% to 12%, with values increasing with increasing water depth (Fig. II.5-15). The grain size distribution at Fourmile Rock ranged from fine sand at the shallow stations along all transects to coarse silt at all deeper stations (Fig. II.5-14). The percent clay increased with increasing water depth, with a tongue of low values extending into the final disposal site (Fig. II.5-15). The values ranged from 5% to 15%.

5.4.4 Commencement Bay--

In Commencement Bay, percent volatile solids ranged from 0.8% to 9.9% (Fig. II.5-16). Contours show a tongue of sediment with values greater than 4% extending from the central basin into the Bay. The stations having %VS levels which exceeded the 95% CI and 1.96 SND extended from the west side of Commencement Bay across the ZSF to Brown and Dash Points (Fig. II.5-16).

The BOD displayed trends similar to those of volatile solids (Fig. II.5-17). A band of high BOD extended from the central basin into a portion of the ZSF with values ranging from 892 to 1338. BOD values decreased in the center of the Bay and increased again on the west side. Stations whose values exceeded the 95% CI also showed trends similar to those shown by volatile solids. A band of stations with BOD exceeding 95% CI, extended across the mouth of Commencement Bay from the west shore to Brown and Dash Points (Fig. II.5-17).

Contour intervals for percent water are presented in Figure II.5-18. The central portion of the study area was composed of sediments containing 50% water. Elevations exceeding the 95% CI and 1.96 SND did not occur in the ZSF (Fig. II.5-18).

The distribution of sediment types in Commencement Bay are presented in Figure II.5-19. The median sediment grain size in most of the ZSF consisted of coarse to fine silt. Closer to Dalco Passage the sediments became significantly coarser. The central portion of the ZSF contained high levels of clay (|15%; Fig. II.5-20).

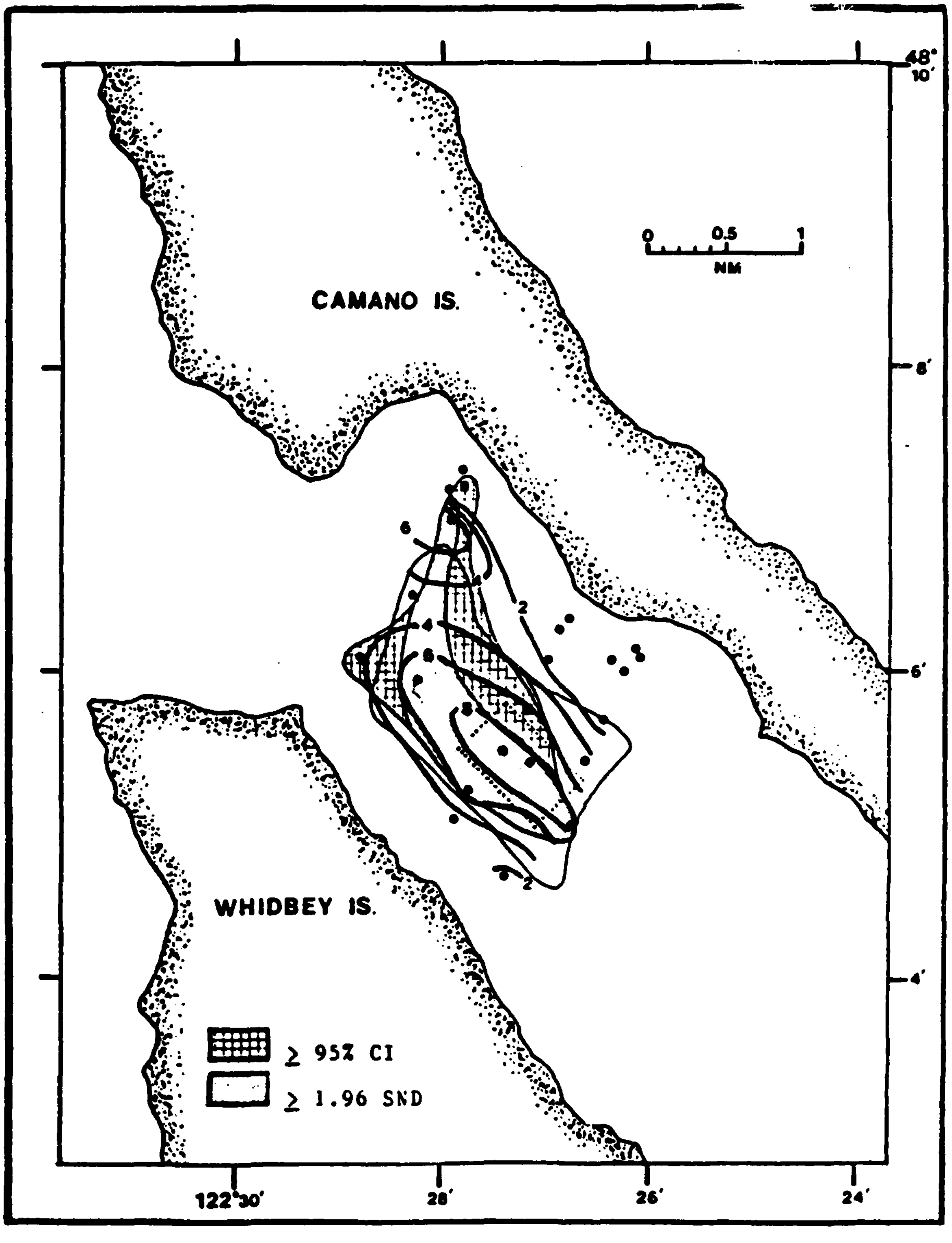


Figure II.5-1 Contours of volatile solids overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

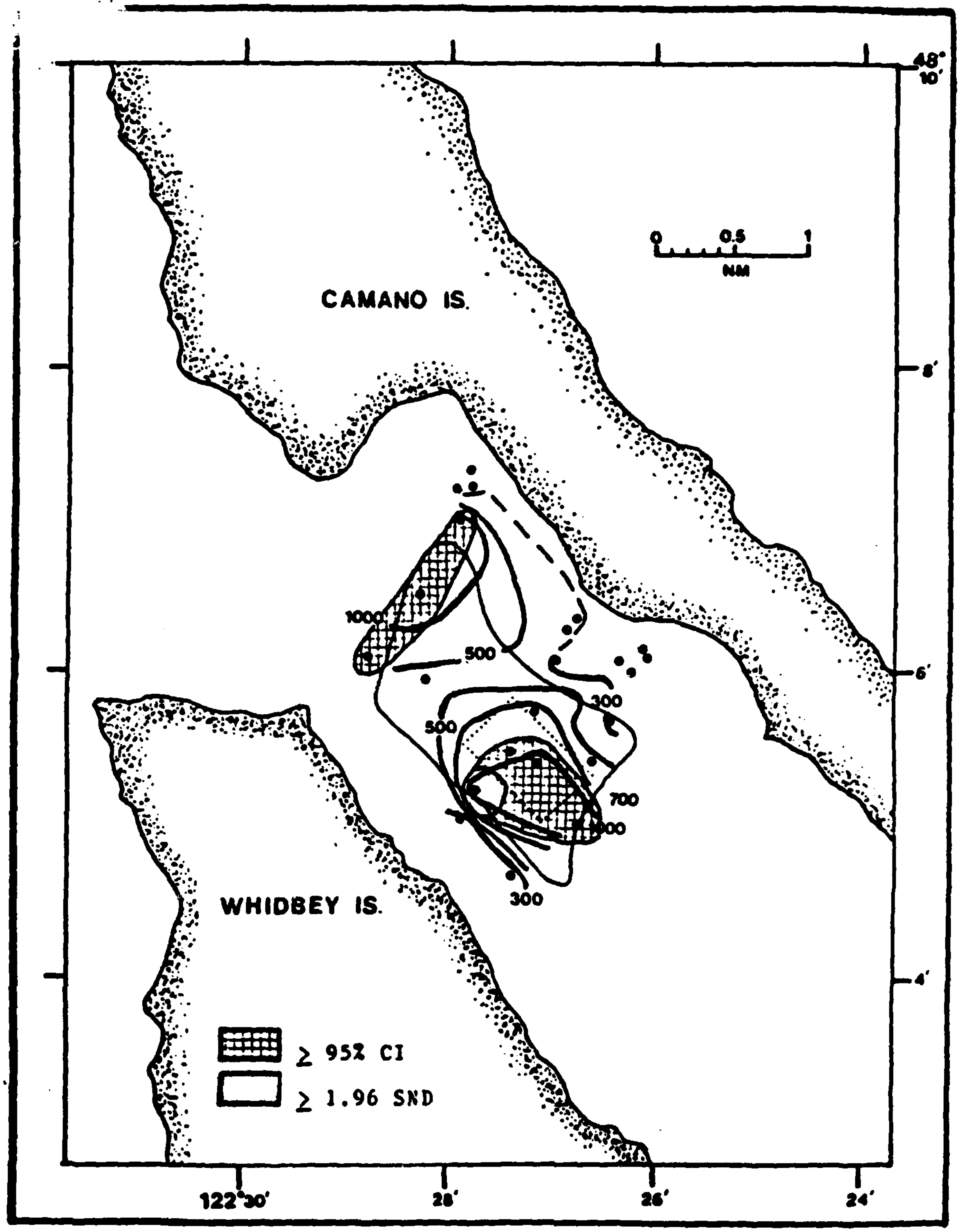


Figure II.5-2 Contours of biochemical oxygen demand overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

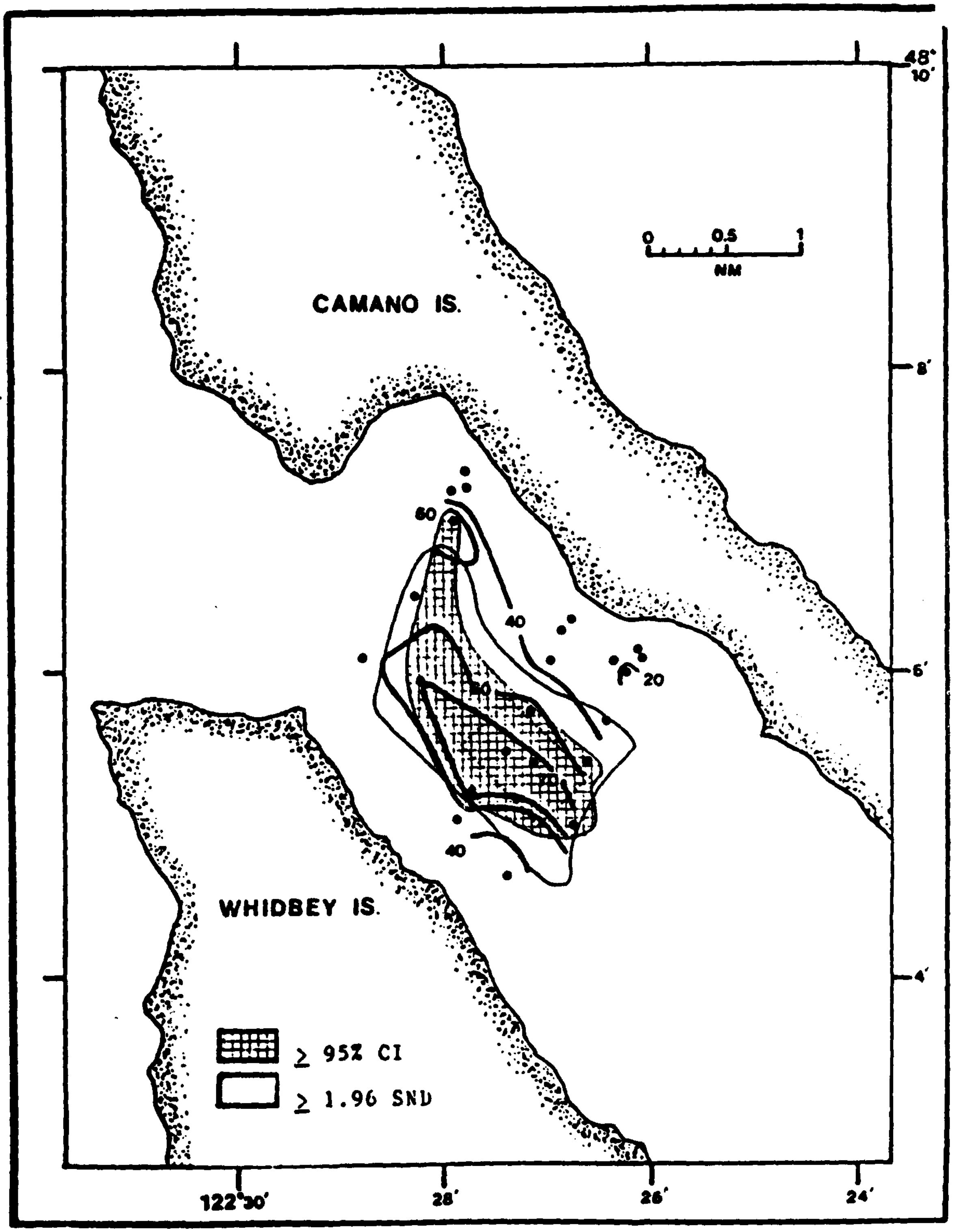


Figure II.5-3 Contours of percent water overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

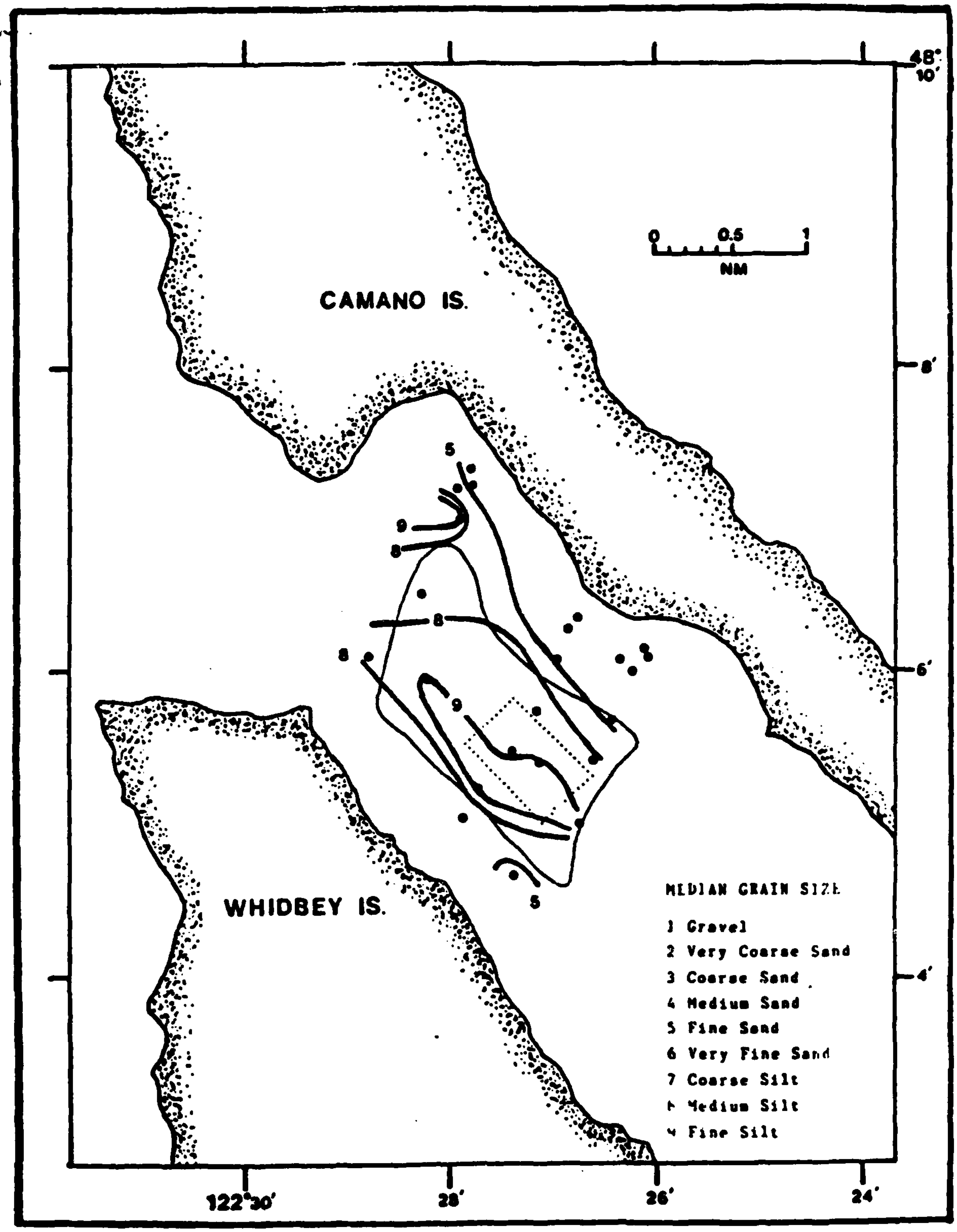


Figure II.5-4 Grain size in the Saratoga Passage ZSF. (Source: Striplin et al., 1987)

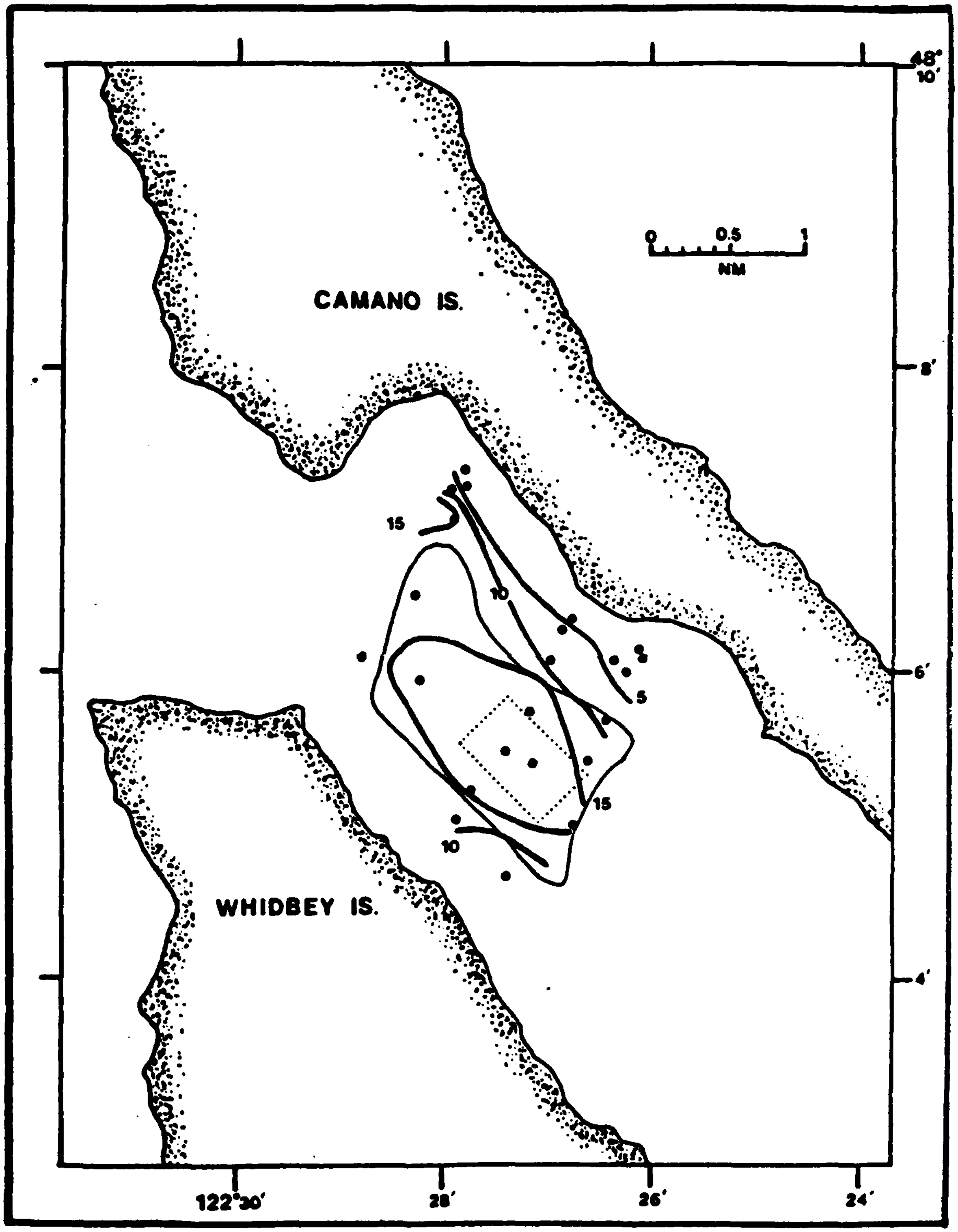


Figure II.5-5 Percent clay in the Saratoga Passage ZSF. (Source: Striplin et al., 1987).

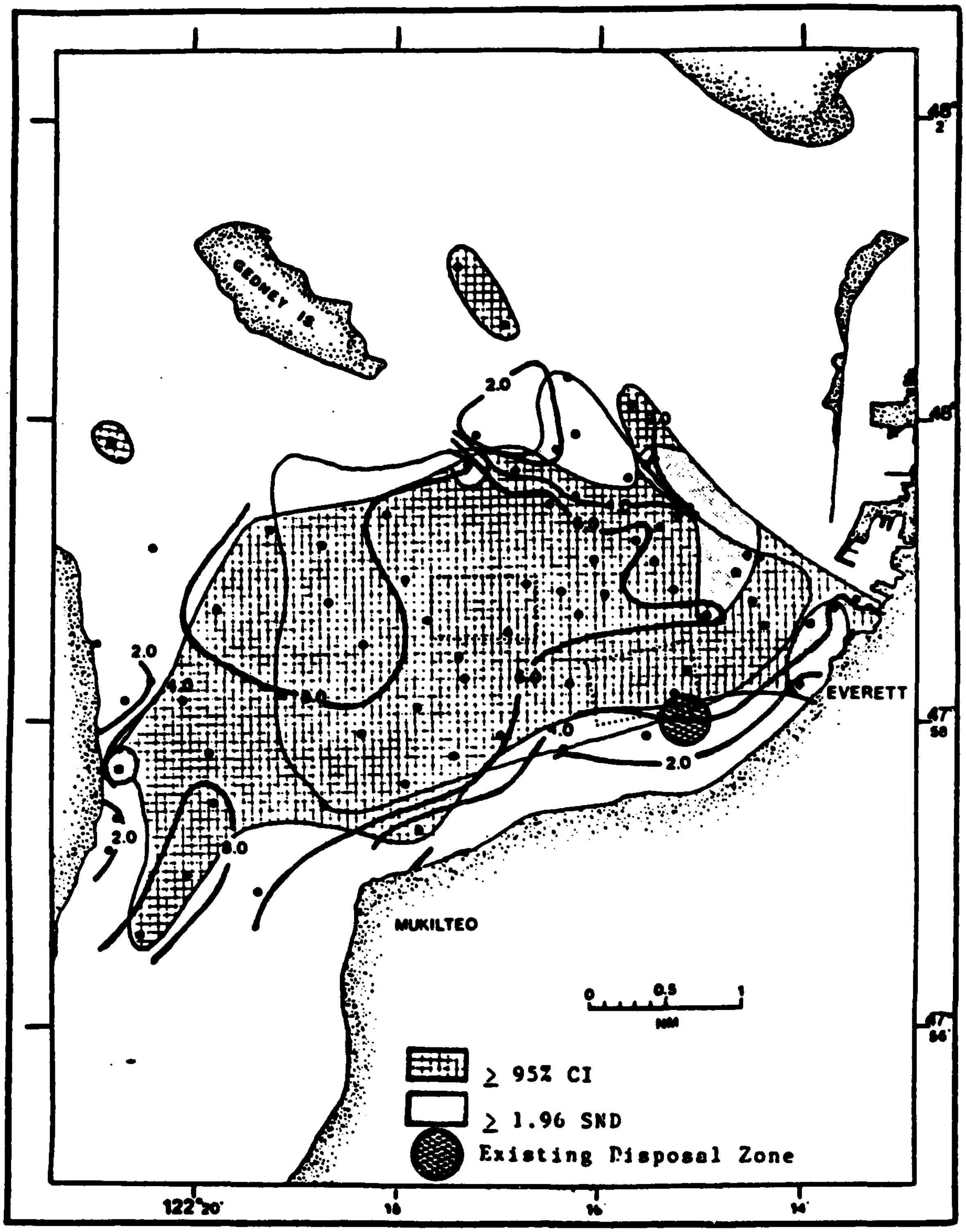


Figure II.5-6 Contours of volatile solids overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

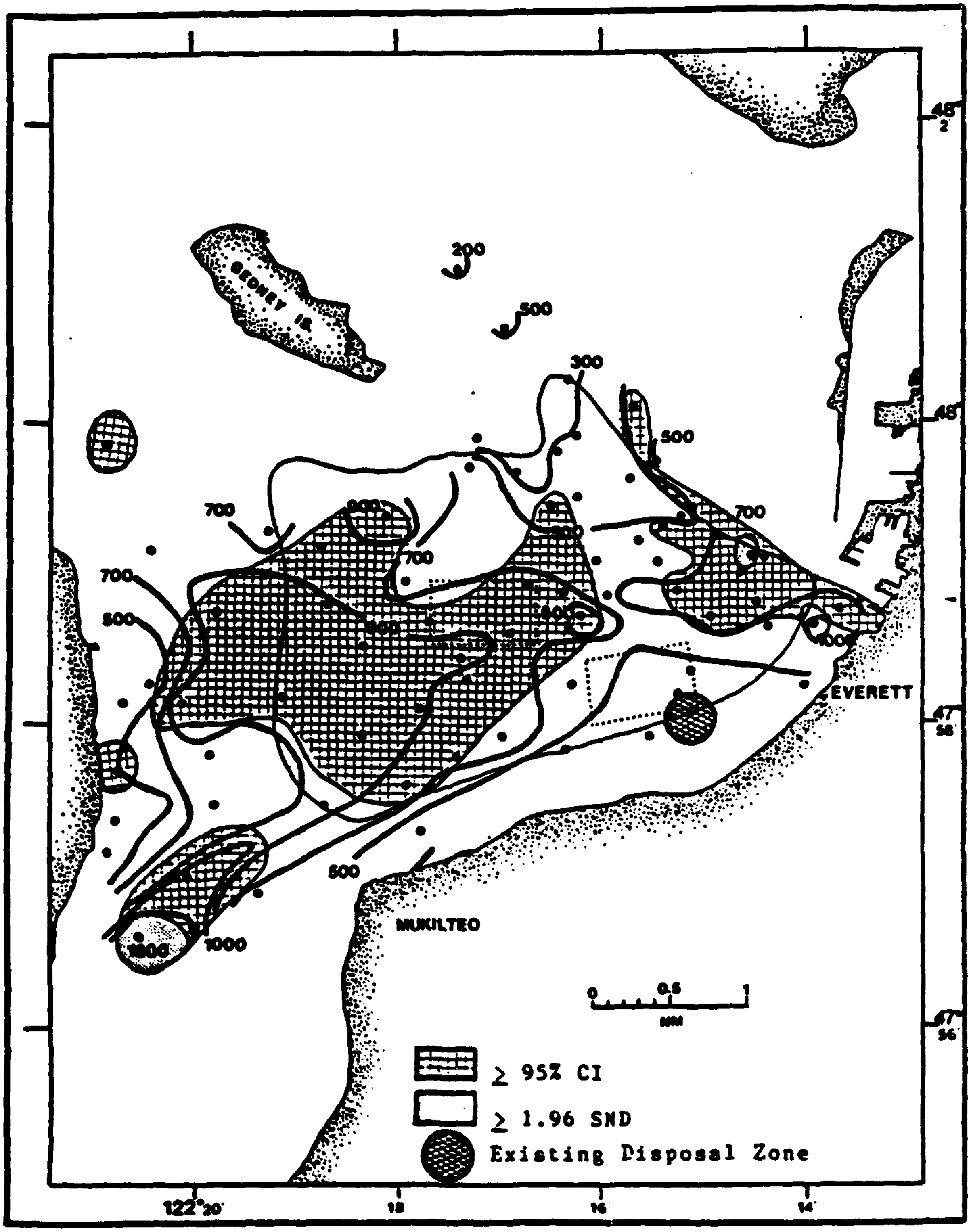


Figure II.5-7 Contours of biochemical oxygen demand overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

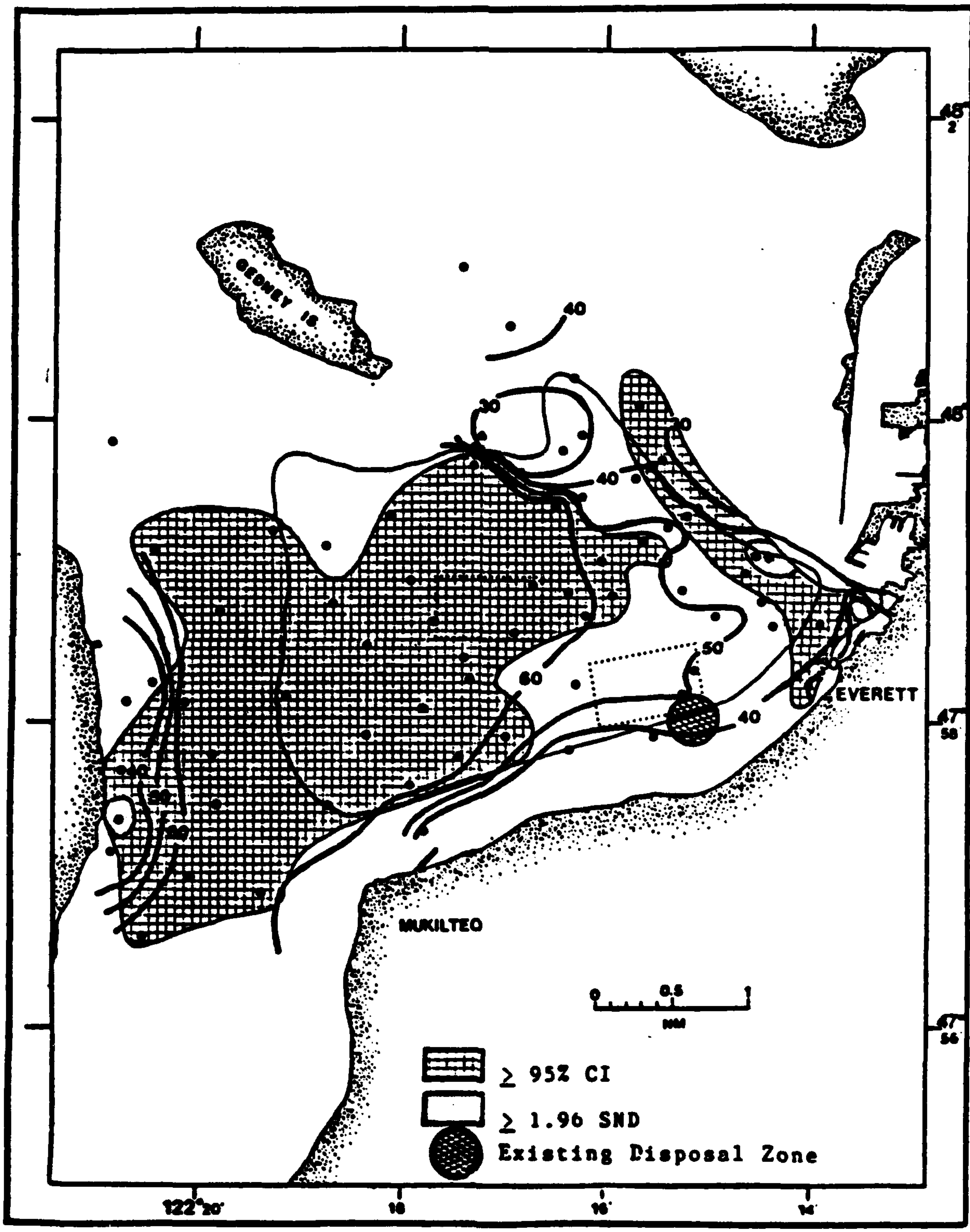


Figure II.5-8 Contours of percent water overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

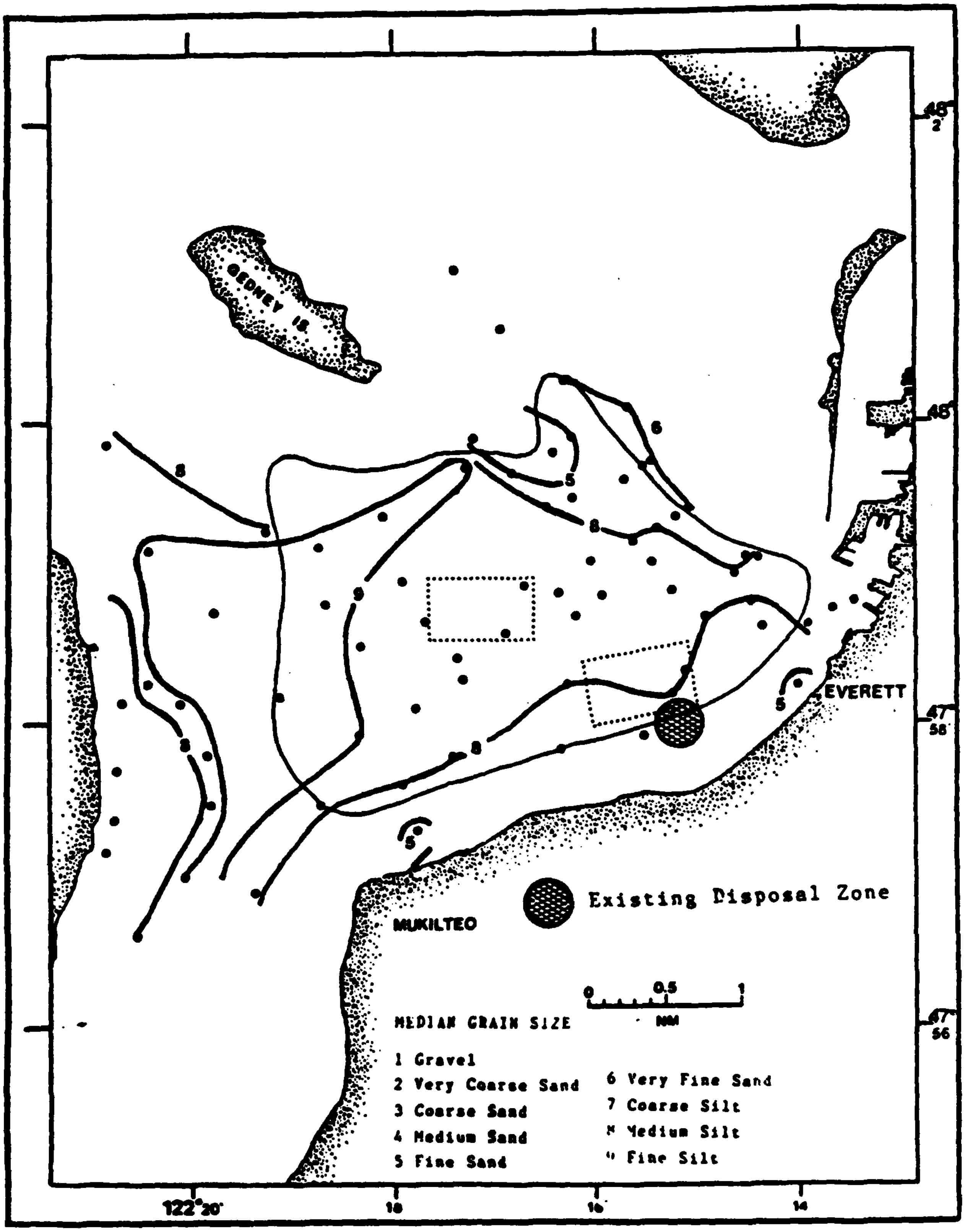


Figure II.5-9 Grain size in the Port Gardner DSF. (Source: Striplin et al., 1987)

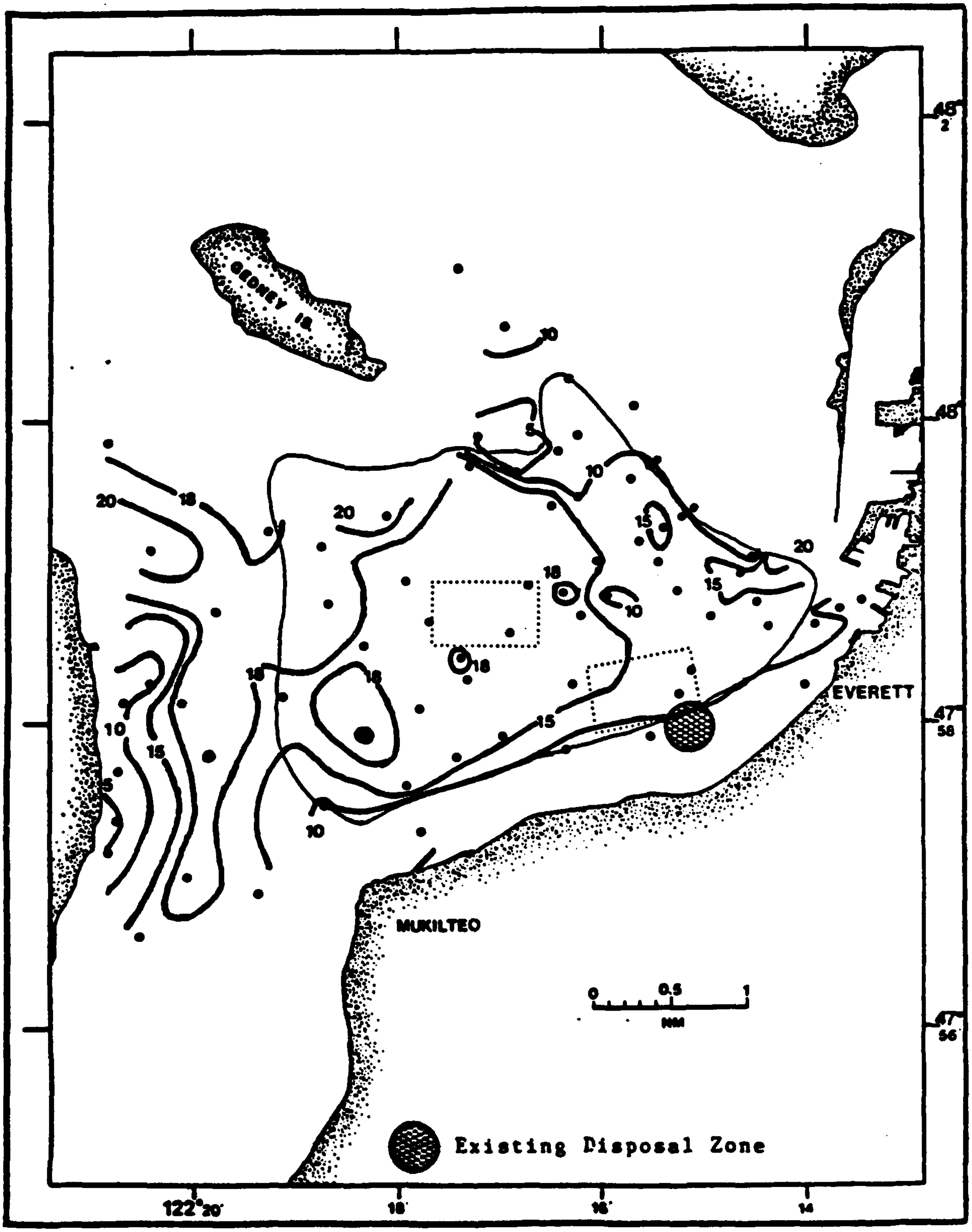


Figure II.3-10 Percent clay in the Port Gardner ZSF.
(Source: Striplin et al., 1987)

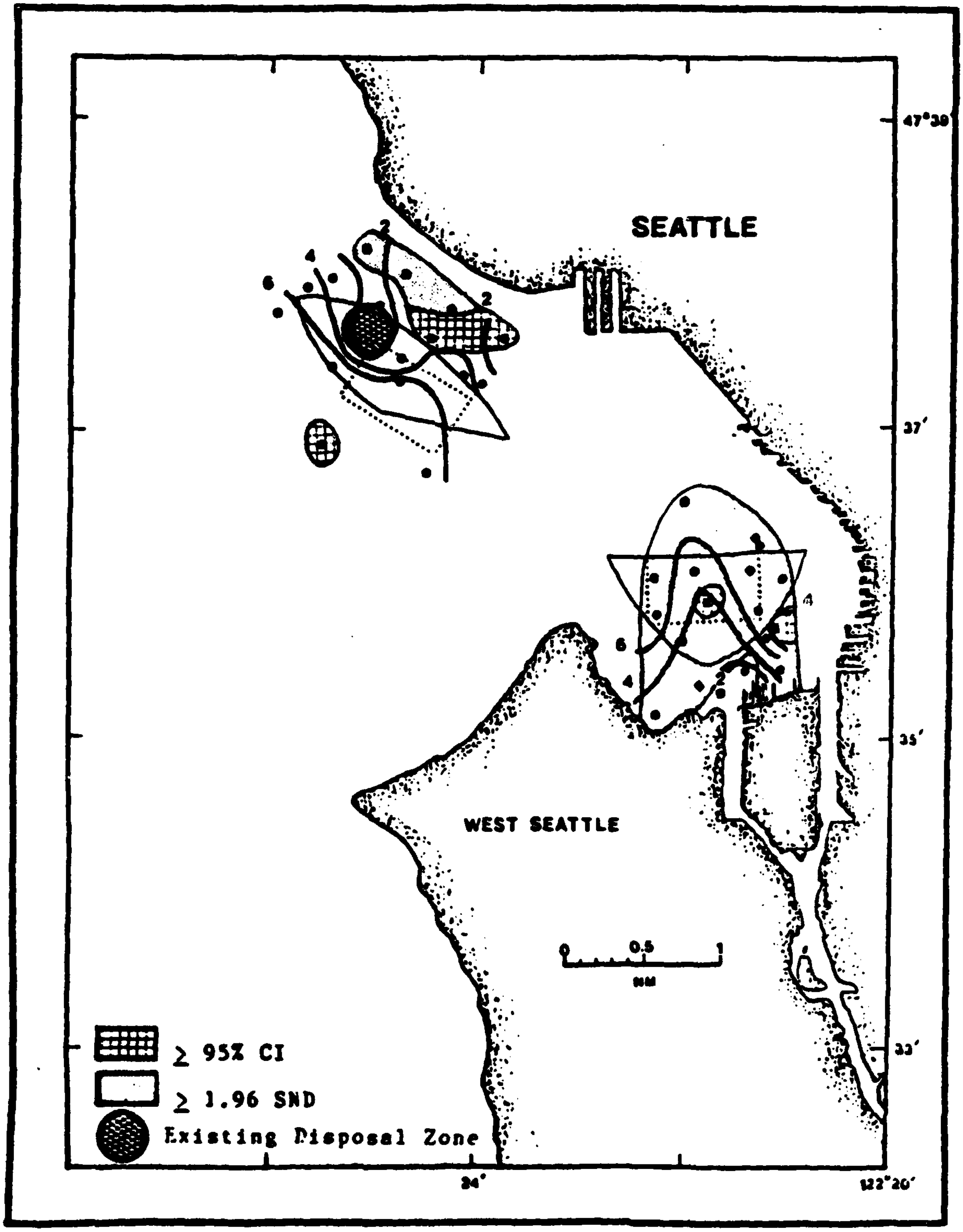


Figure II.5-11 Contours of volatile solids overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

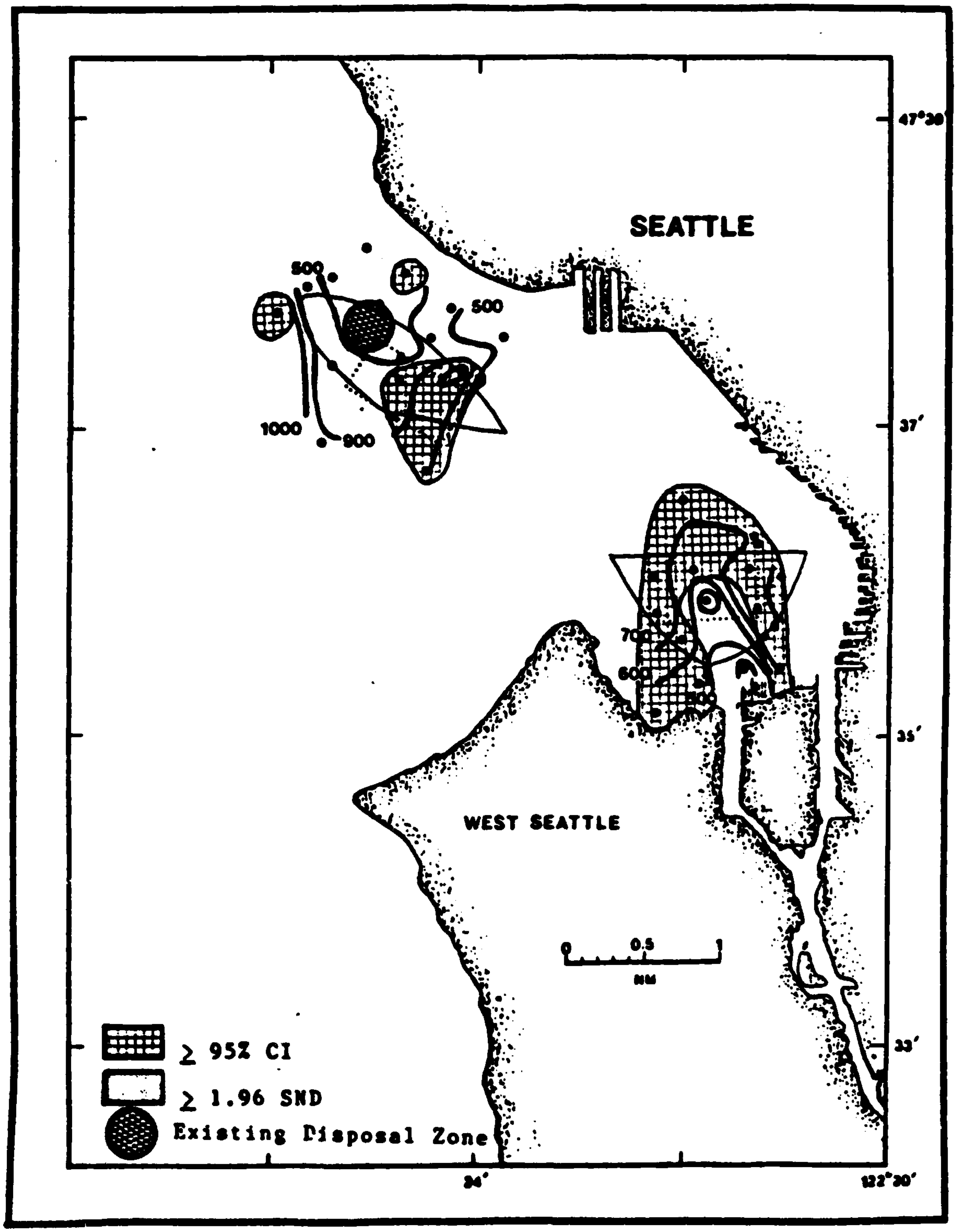


Figure II.5-12 Contours of biochemical oxygen demand overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

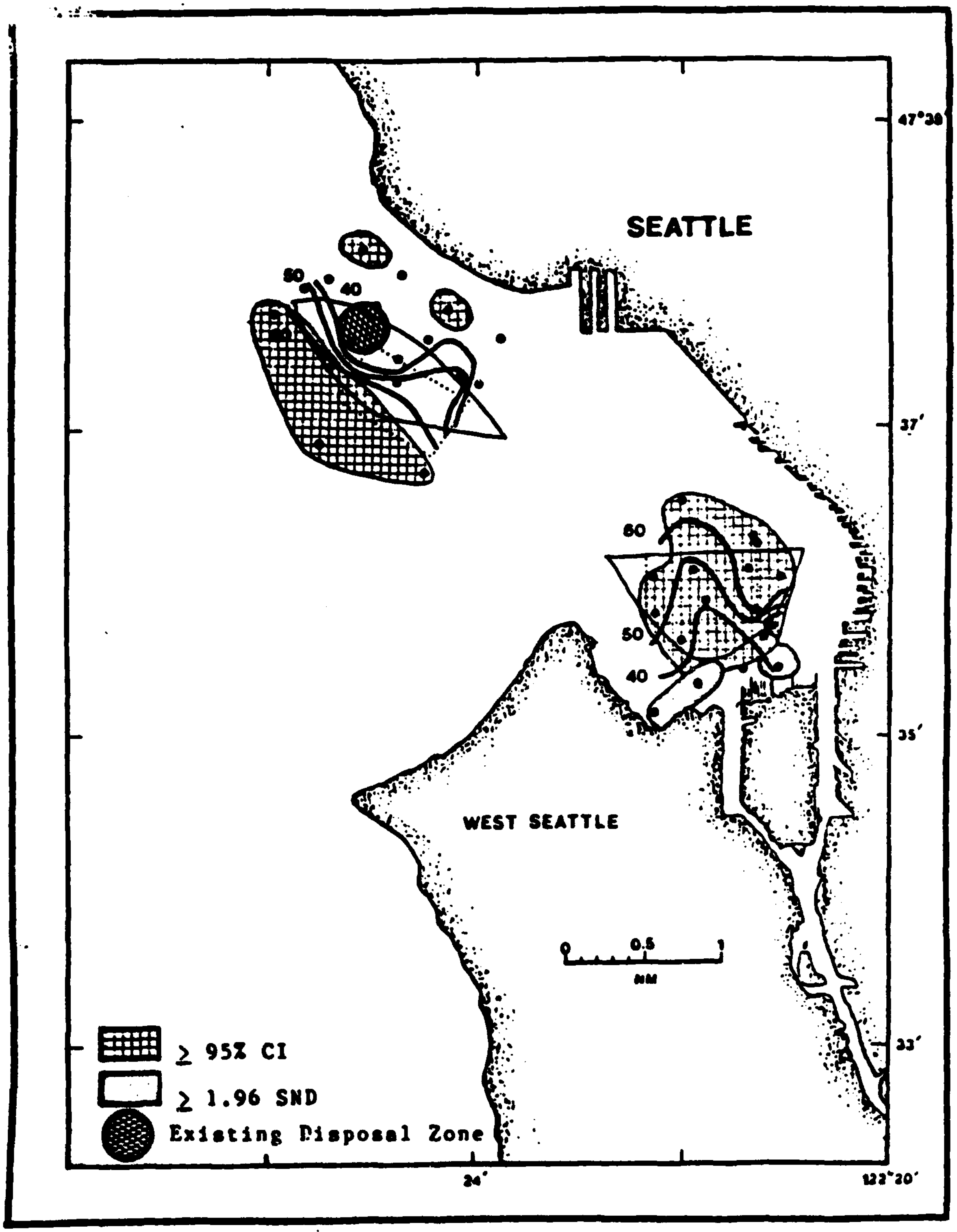


Figure II.5-13 Contours of percent water overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

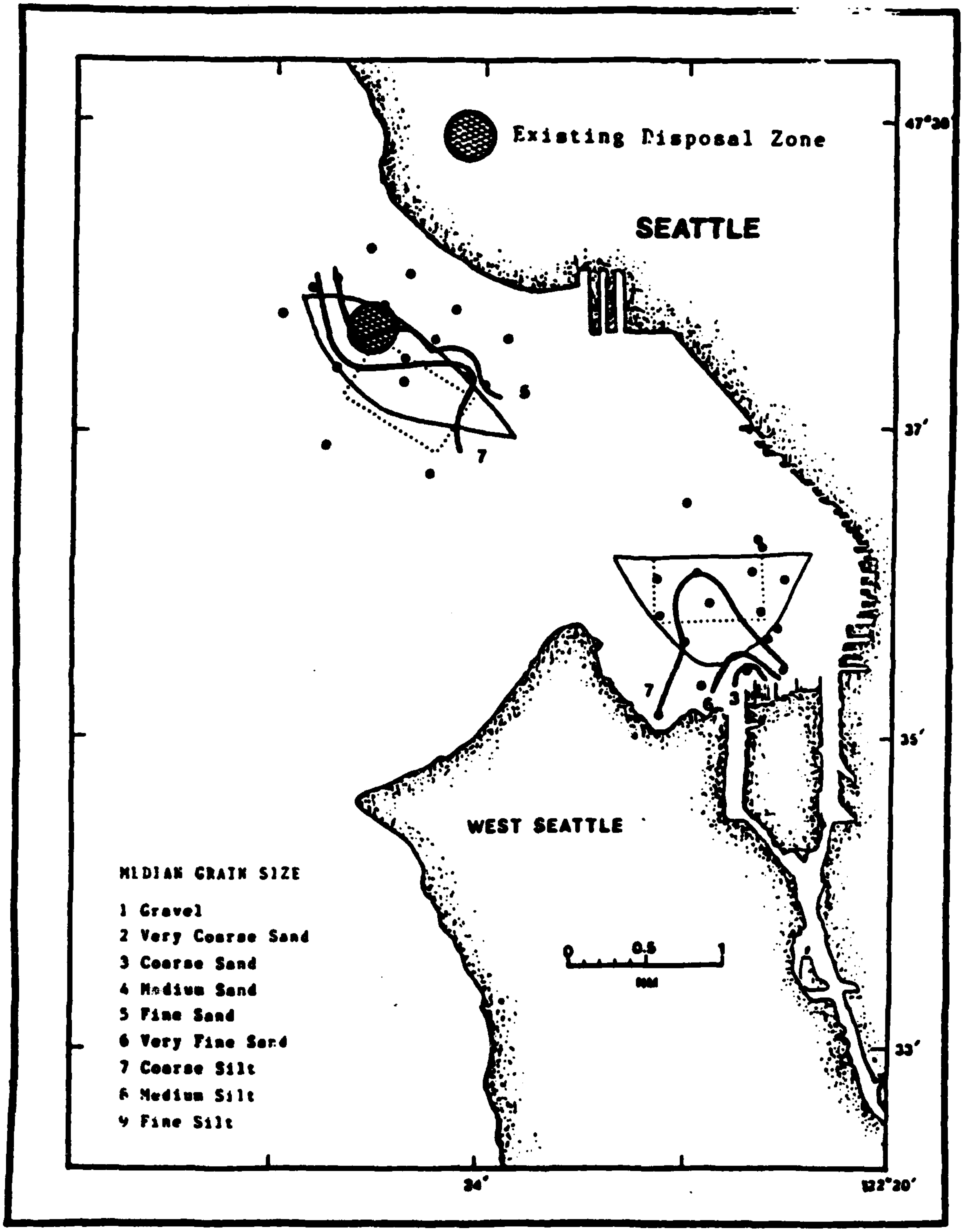


Figure II.5-14 Grain size in the two Elliott Bay ZSFs. (Source: Striplin et al., 1987)

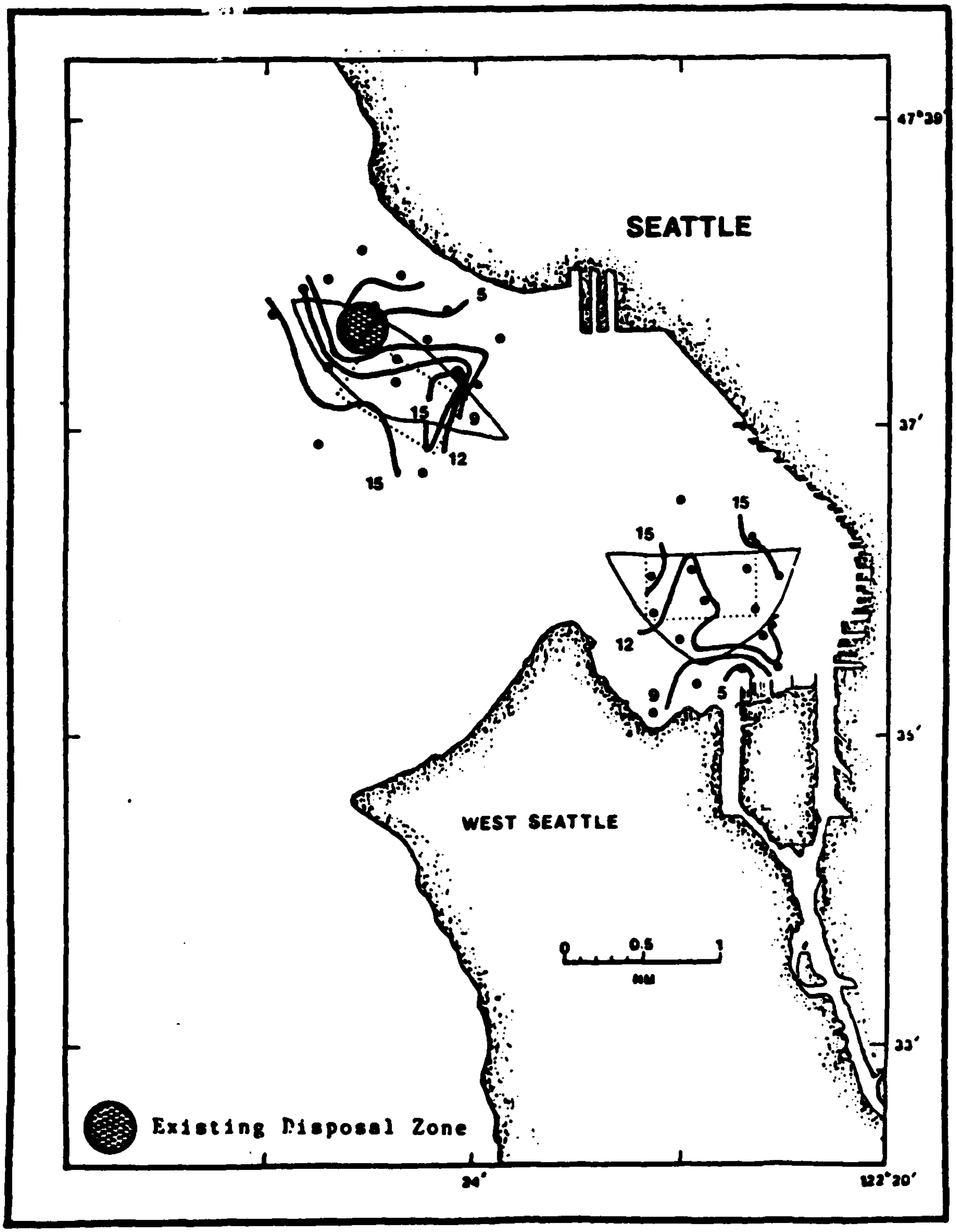


Figure II.5-15 Percent clay in the two Elliott Bay ZSFs. (Source: Striplin et al., 1987)

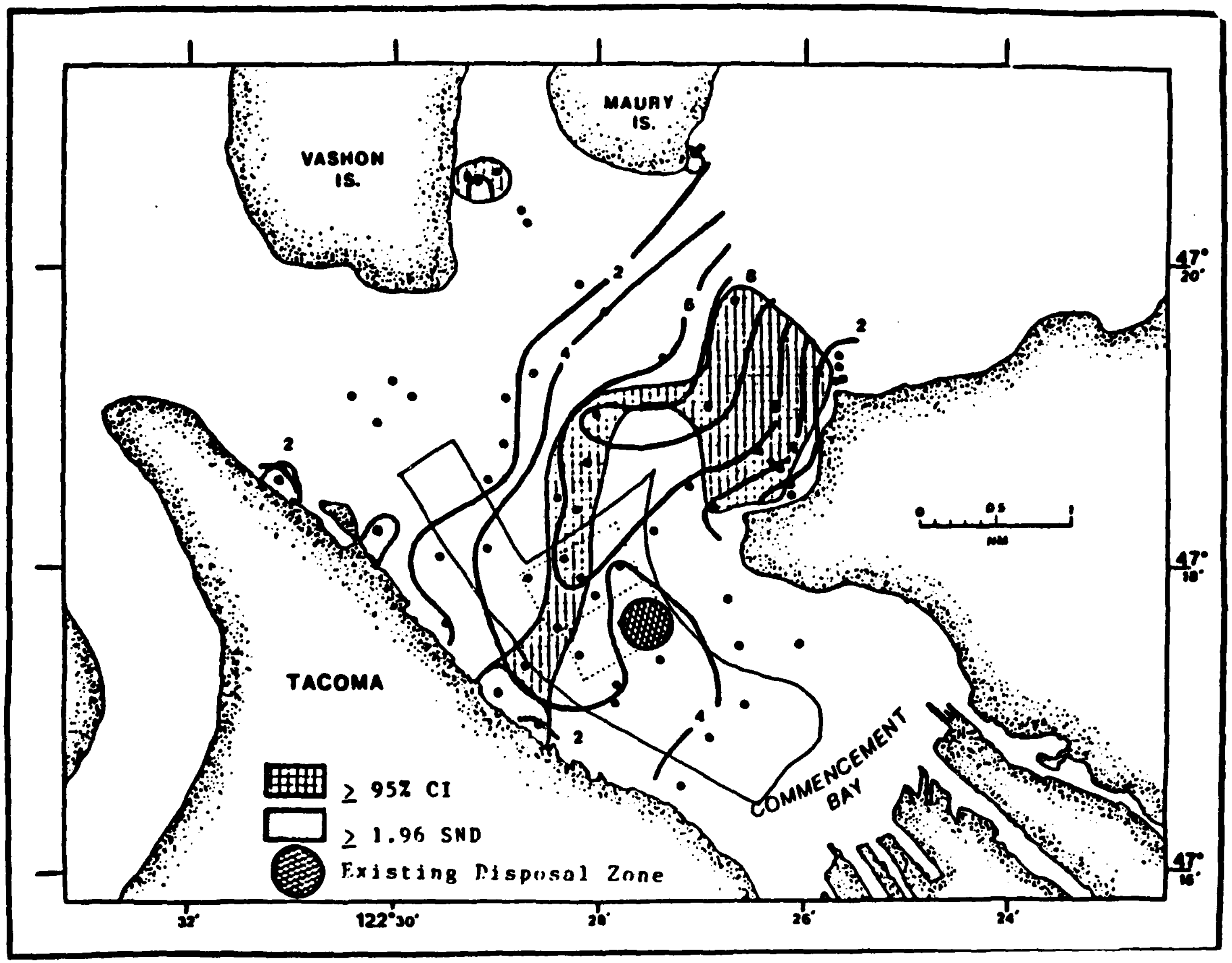


Figure II.5-16 Contours of volatile solids overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

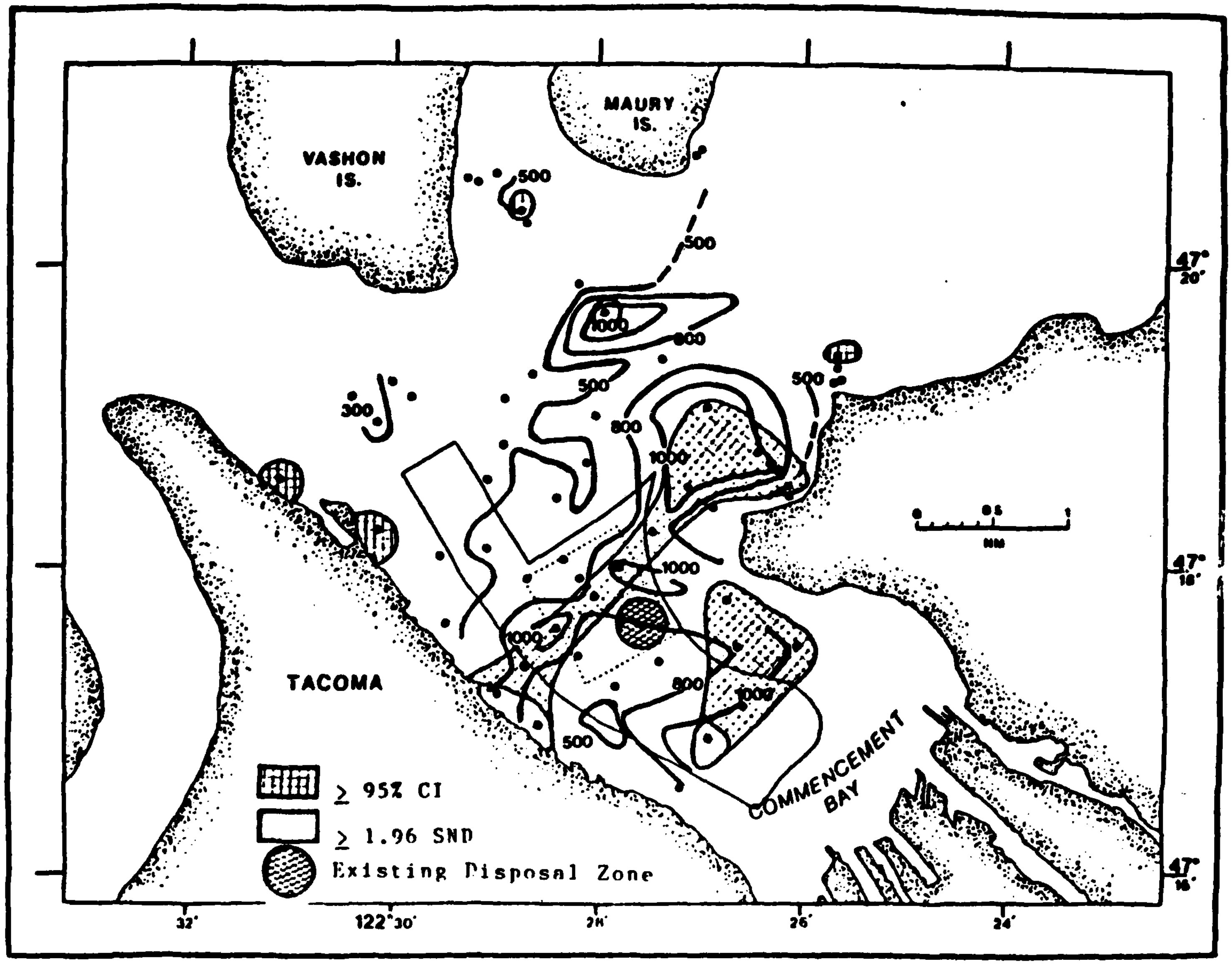


Figure II.5-17 Contours of biochemical oxygen demand overlayed with areas where values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

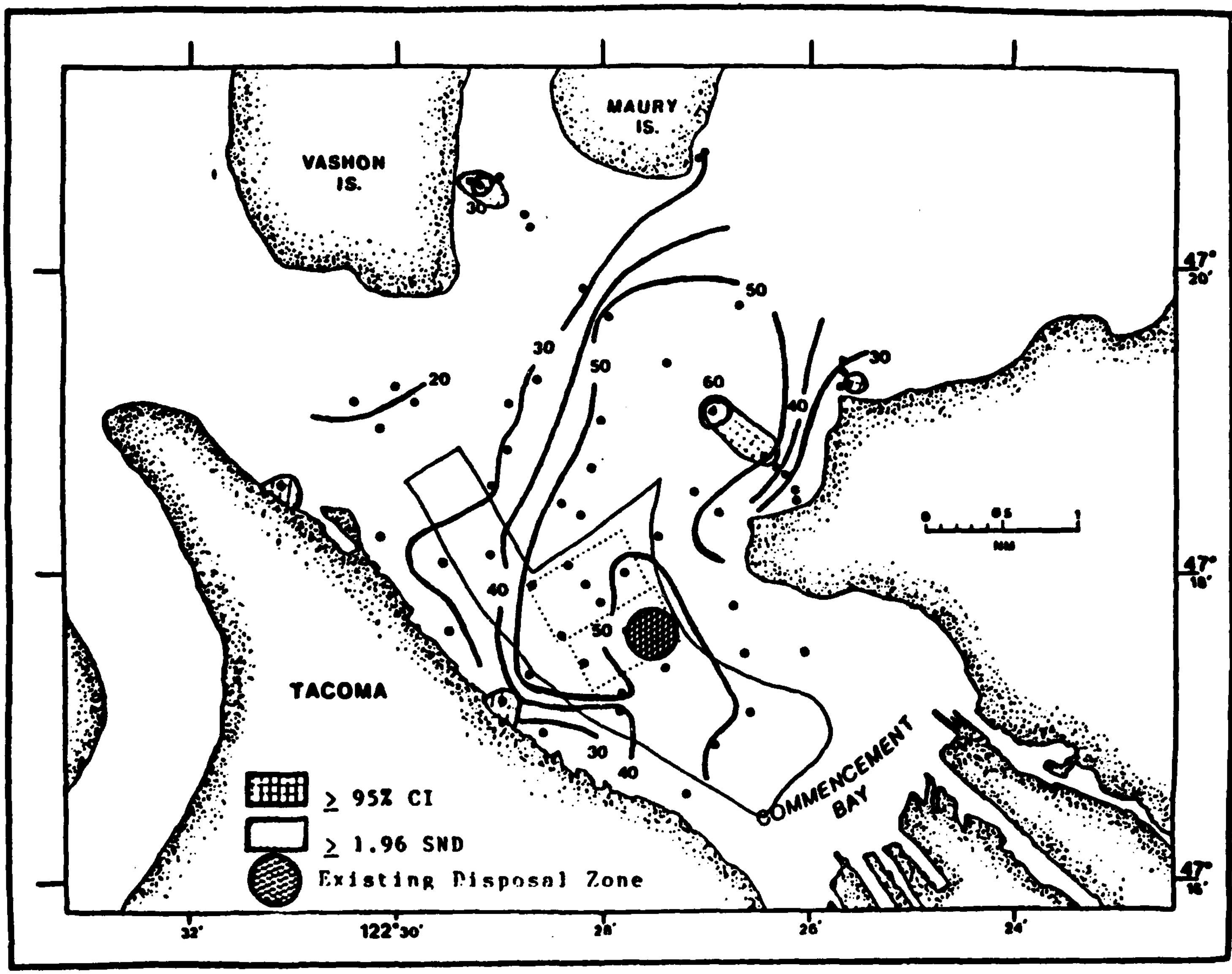


Figure II.5-18 Contours of percent water overlayed with areas were values exceed the 95% CI and 1.96 SND. (Source: Striplin et al., 1987)

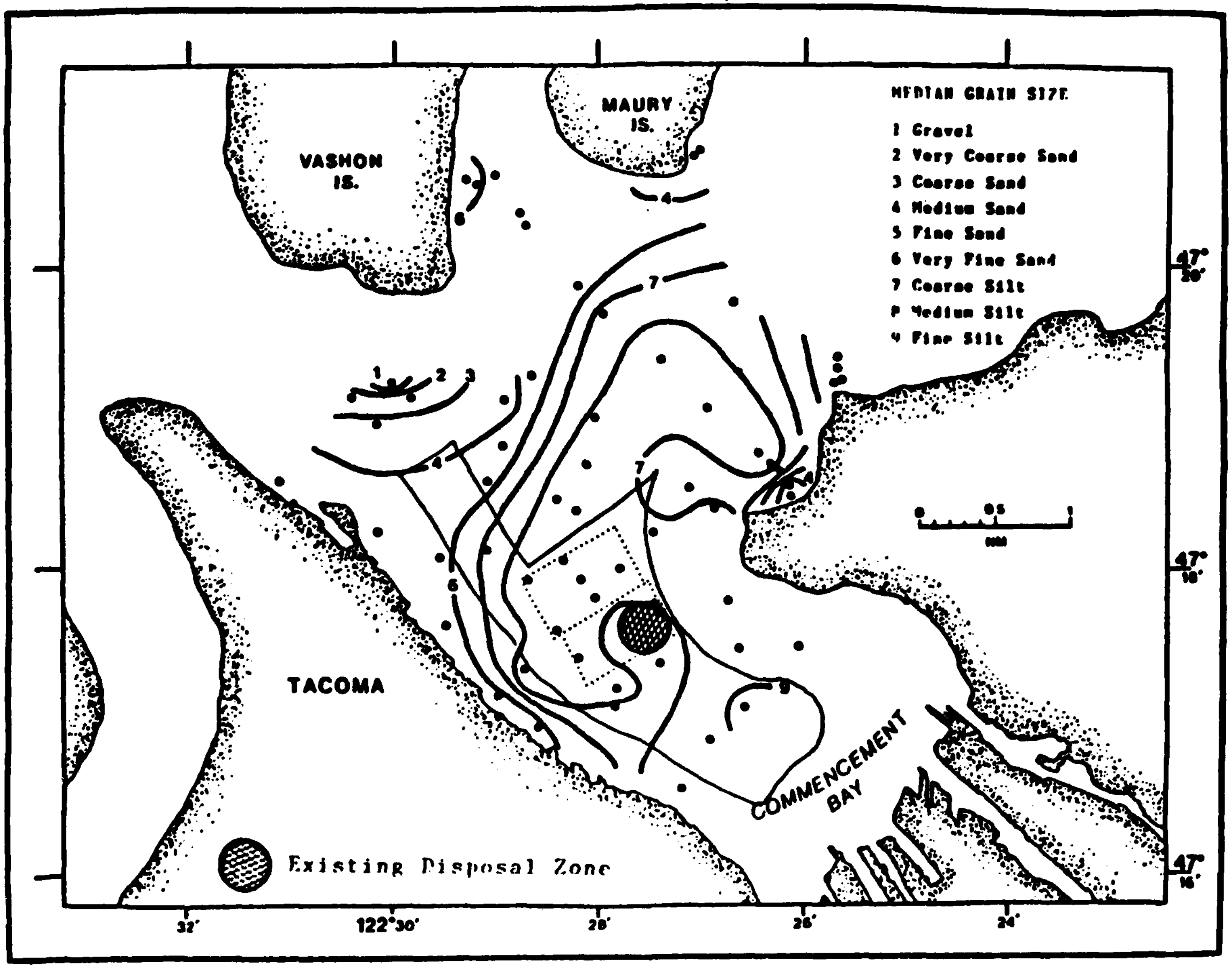


Figure II.5 19 Grain size in the Commencement Bay ZSF.
(Source: Striplin et al., 1987)

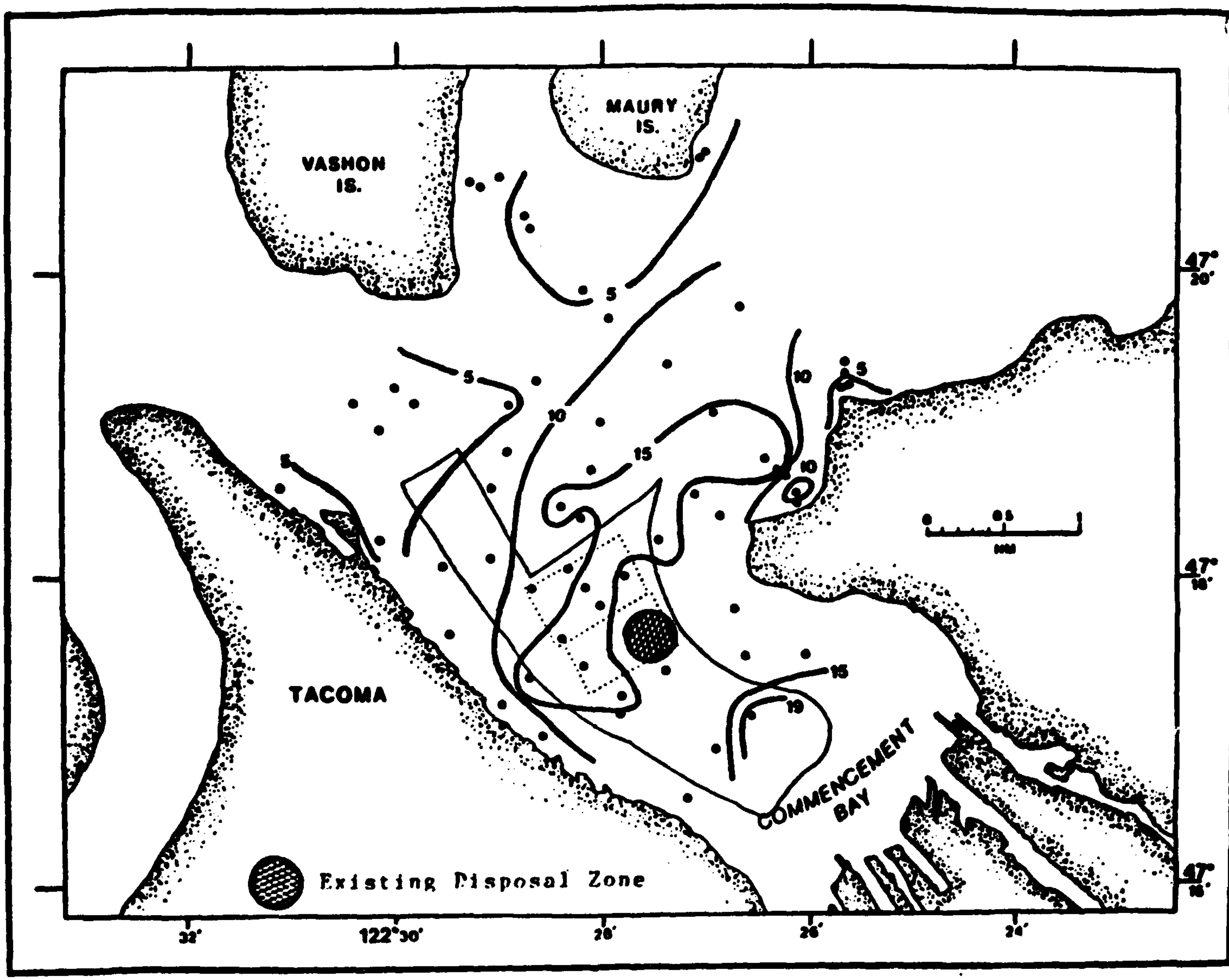


Figure II.5-20 Percent clay in the Commencement Bay ZSF.
(Source: Striplin et al., 1987)

6. HYDRAULIC CHARACTERISTICS

6.1 Objective

In the previous two sections it is evident that there are areas where natural sediments tend to deposit and that the size of the preliminary disposal site fits within these areas. The central question is whether the dredged material would remain in these areas if placed there. In the next section it will be seen that newly deposited dredged material containing large amounts of silts and clays begins to erode when the current speed exceeds a threshold of approximately 25 centimeters per second (0.5 knot; 0.85 feet per second). As a result, PSDDA sought areas where natural sediments tended to accumulate and where extreme speeds were less than 0.85 feet per second. Therefore, in this section, maps of current strength and direction were prepared for the ZSFs.

6.2 Methods

Current strength was determined using three approaches: field data were examined; estimates were generated with a numeric model; and estimates were also generated with a hydraulic model.

6.2.1 Historical Field Data--

Figures II.6-1 - II.6-4 show the locations in the ZSFs where current speed and direction have been measured. In Figures II.6-1 - II.6-4 the dots indicate the locations of measurements, and circled dots indicate locations which were used in correlations described later.

Although there is not a ZSF in Seahurst Bay, the many measurements made there were readily available and were used in the correlations; therefore, the locations of those measurements have been shown in Figure II.6-5.

The results presented in this chapter are based on several hundred current meter records. A record is defined as one obtained at a particular depth over a given duration, or the approximate time between installation and retrieval of a current meter. Nearly all of the records were obtained using Aanderaa current meters attached to moorings. These were anchored to the bottom and held taut with a subsurface float. Usually several current meters were attached to a mooring at various depths, so that a number of records were often obtained at a given latitude and longitude over the same interval of time.

These records have been utilized in previous studies and are known to be of good quality. The methods used to process the records have been described elsewhere in some detail and will not be repeated here. The reader should consult the following reports for descriptions. In Saratoga Passage the records are described by Cox et al. (1984). In Port Gardner the records are described in three reports: 1) Cox et al. (1984) for data taken prior to 1978; 2) Nortec (1986) for data taken in the vicinity of the proposed Navy disposal site; and 3) Evans-Hamilton, Inc. (1986) for data taken at the existing disposal site. In Elliott Bay the data have been described in three reports: 1) Cox et al. (1978) for data taken prior to 1978; 2) URS and Evans-Hamilton, Inc. (1986) for data taken for the Municipality of Metropolitan Seattle (Metro); and 3) Nortec (1985) for data recently taken for Metro in the vicinity of Alki Point. In Commencement Bay the records have been described by Ebbesmeyer et al. (1984). Finally, in Seahurst Bay the records have been described by URS and Evans-Hamilton, Inc. (1986).

6.2.2 University of Washington Hydraulic Model--

The hydraulic model was constructed at the University of Washington as described by Lincoln (1979). Prior to construction, a detailed theoretical study was made to investigate suitable model scales. The primary requirement for proper representation is that flow must be turbulent. Normally, turbulence is a function of both channel dimensions and speed of flow. In Puget Sound, the channels are irregular and flow speeds are variable from near zero to several knots, depending on tidal characteristics and time of tide. To be conservative, straight and uniform channels were assumed in this theoretical study. Additional considerations were the ultimate size of the model, available space, and cost of construction. These studies resulted in the selection of a horizontal scale of 1:40,000 and a vertical scale of 1:1,152. From these two scales, all others were derived from mathematical relationships for the propagation of a shallow water wave (Rattray and Lincoln, 1955). The depth scale is exaggerated by a factor of 34:7. This was necessary to achieve turbulent flow in the principal channels except during periods of slack water and to reduce the effect of surface tension in shoal areas such as tidal flats.

Tidal action is a principal driving force of the dynamic oceanographic processes occurring in Puget Sound; thus, they were represented accurately in the hydraulic model. The tide computer constructed for the model is the Kelvin type, similar in principal to the machine used until 1966 by the U.S. Coast & Geodetic Survey for preparing the published Tide Tables. The computer for the model provides summation of six cosine functions representing six major tidal constituents. Tides for any specific calendar period can be computed with an accuracy governed by the limitation of only six constituents, while at least 37 are used in computing the published tide predictions.

Puget Sound receives a volume of fresh water each year from river discharge, amounting to approximately 20% of its total volume. The strong tidal currents and turbulence mix the fresh water and seawater. The inflowing river water must escape to the ocean and in doing so, as a result of mixing, carries with it about nine to ten times its volume of seawater. To compensate for the loss of salt and seawater, and to maintain the salt budget, there is an inflow of more saline water from the Strait of Juan de Fuca. Because the mixed water is of lower salinity and therefore of lower density, a net outflow occurs near the surface and a net inflow at depth. A wide range of surface salinities and vertical salinity gradients occur that varies with both location and time.

Fresh water inflow to the model is provided at the locations of the eleven principal rivers discharging into Puget Sound. Model river flow is manually controlled with discharge rates of each river indicated by individual flow meters. A separate tank simulates the ocean as a source of salt water. The model's seawater is continually circulated between the ocean tank and the model. Conductivity of the ocean water is monitored and compared with a standard. A concentrated salt solution is added by automatic control as required to compensate for dilution by river discharge and to maintain the ocean salinity at the control value.

Because of the small size of the hydraulic model considerable efforts have been made in the past to verify that it reproduces tidal phenomena seen in the field (Rattray and Lincoln, 1984; Ebbesmeyer et al., 1984). In this appendix, total variance was computed from currents measured in the hydraulic model and mapped in two of the ZSFs. To verify the variance Ebbesmeyer et al. (1984) estimated variance from field data and compared the results with variance computed from the model (Fig. II.6-6). In Figure II.6-6 the dots represent variance averaged over the water column when several current meter records were available at a single location, and the x's represent variance computed at the surface of the hydraulic model. Despite the scatter, there is general agreement between field and model data. Much of the scatter undoubtedly occurs because the field data were obtained under varying tide, wind, and runoff conditions; whereas the model results represent only spring tidal conditions at the water surface under high and low runoff.

6.2.3 Numerical Tidal Current Model--

In addition to the hydraulic model, a numerical model of tidal currents was also used for PSDDA. A two-dimensional vertically integrated set of equations was utilized as described by Butler (1980). The detailed development of the equations, as well as a review of literature pertinent to the numerical model

was presented by Schmalz (1983; 1986). Although a compatible three-dimensional hydrodynamic and sediment transport model has been developed by Sheng (1983), due to PSDDA's economic and time constraints the two-dimensional, vertically integrated approach was undertaken.

In developing the grid for Puget Sound, two global grid alternatives were considered. In the first alternative, spatial resolution was chosen to be 1,500 feet which roughly corresponds to the size of the preliminary disposal site. A grid of this resolution would require approximately 15,000 cells to cover Puget Sound. The maximum water depth in Puget Sound is approximately 900 feet. With this information the gravity wave speed and the explicit time steps were calculated to be 170 feet per second and 8.8 seconds, respectively. An implicit time step of 60 seconds was considered. Over 5,700 time steps would be required for a four day simulated period at 1,440 time steps per day. To perform this number of operations over a 15,000 cell grid was considered too costly. Therefore a second grid was considered with a spatial resolution of 3,750 feet. A time-sharing program was used to develop a 70 x 103 grid totaling 7,210 cells. Because of a reduction from approximately 15,000, to approximately 7,000 cells, a simulation period of five days would require 4,800 time steps at 960 time steps per day. This second alternative was deemed acceptable.

Puget Sound depths were taken from NOAA Nautical Chart 18440 for Admiralty Inlet and Puget Sound, and Nautical Chart 18421 for the Strait of Juan de Fuca to the Strait of Georgia. Because of Puget Sound's configuration, water depths fluctuate rather abruptly from one cell to the next. For this reason, depths in many cells were averaged to obtain representative cell depths. A number of small islands are located in areas that obstruct water flow; therefore, barriers were added to make the boundaries more precise. In some instances points were idealized to represent either land or water that were crucial in the model. All barriers were located on cell faces and assigned a land elevation of ten feet. The barriers are modeled as exposed barriers; that is, no overtopping occurred at any barrier during the simulations.

The tidal signals along the open water boundary were specified at the two entrances to Puget Sound: Admiralty Inlet and Deception Pass. Of the total 37 tidal constituents available from National Ocean Survey, twelve were initially considered. In the simulations, the amplitudes and phases of the two long period constituents were set to zero since meteorological effects were not considered in this study.

To investigate the numerical behavior of simulated water surface elevation throughout Puget Sound, 28 stations were considered. To compare simulated currents with predicted values based upon the harmonic constants, 38 current stations were utilized. Tidal currents were reconstructed based upon six of the tidal constitutents used at the open boundary; therefore,

four of the open boundary constituents were not used to predict the currents. Consult Schmalz (1986) for a discussion of bottom friction coefficients.

A spring tide occurred during January 16-18, 1981 and was used to calibrate the model. While simulated results at Seattle showed close agreement to predicted values in amplitude and phase, at Olympia the simulated and predicted phase showed a lag of 2-3 hours.

Vertically averaged currents from the model, based upon ten short period constituents, were compared with values obtained from field measurements. The field data were analyzed to determine the three largest semi-diurnal and diurnal tidal constituents. These constituents were used to obtain a comparison with the numerical model. Figure II.6-7 shows inter-comparisons between current speeds computed from field data and from the numeric model at the four locations closest to the ZSFs (Fig. II.6-8). In three locations the agreement is good (Saratoga Passage, Port Gardner, and in the Main Basin), while the discrepancy near Commencement Bay between peak speeds is sizeable (approximately 0.5 feet per second). Despite these discrepancies, it will be seen later that the regional patterns of peak speeds predicted by this model are in reasonable agreement with those computed from the hydraulic model.

6.3 Current Strength

The strength of currents in Puget Sound have been estimated in a number of ways. Various investigators have examined mean speed, total variance, and peak speeds (Cox et al., 1984; Ebbesmeyer et al., 1984). These terms are defined as follows. Mean speed is the mean of all speeds in a current meter record regardless of direction. Total variance is the sum of the variances determined for the two component directions (north-south; east-west). The square root of the variance gives the standard deviation of the current which is another useful measure of current strength. As it turns out below it is nearly equal to the mean current speed. Peak speeds are estimated in various ways, some investigators determining the fastest speed in a record and others looking for a high percentile, say the speeds that occur during a small percentage of time. To simplify the PSDDA investigation, relations were investigated between the mean, variance, and a selected percentile of the peak speed.

6.3.1 Interrelations between the mean, variance, and peak currents--

For this investigation nearly 200 current meter records were utilized, using available mean, variance, and peak speeds. The terms are defined mathematically as follows:

1) mean speed $= \frac{1}{n} \sum_{i=1}^{n} Si$,

where Si is the magnitude of the current velocity and the current meter record contains n observations.

2) Total variance $= \frac{1}{n} \sum_{i=1}^{n} (ui - u)2 + (vi - v)2$,

$$\bar{u} = \frac{1}{n} \sum_{i=1}^{n} ui , \qquad v = n^{1} \sum_{i=1}^{n} vi ,$$

where ui, vi are the east-west and north-south components of the velocity, respectively. The rms (root mean square) speed is defined as the square root of the total variance.

3) Peak speed. For this study the peak speed is defined as the speed above which there are 1% of the observations. In other words, if there are n observations in a current meter record, the peak speed is the threshold above which there are 0.01 times n observations.

Figures II.6-1 - II.6-5 show the locations in Puget Sound where currents were observed and utilized to determine the interrelationships. It can be seen that many of the observations were taken in or near the ZSFs and that the observations occurred in environments varying from near the heads of bays where currents are weak, to the mid-channel areas where currents are strong. The observations were taken over a wide range of depths and durations (Fig. II.6-9).

Figures II.6-10, II.6-11a, and II.6-11b show graphs of mean versus rms speeds, mean versus 1% speeds, and rms versus 1% speeds, respectively. Linear regressions were computed for each graph with the following results. For mean versus rms speeds (Fig. II.6-10) there were 170 records and the linear regressions explained 86.5% of the variance between these two quantities.

For the mean versus 1% speeds (Fig. II.6-11a) there were 176 records, and the linear regression also explained 86.5% of the variance. For the rms versus 1% speeds (Fig. II.6-11b) there were 176 records, and the linear regression explained 77.4% of the variance. These results indicate that the three measures of current strength are well correlated.

Given the correlations amongst the three measures of current strength, it appears that the equations of the linear regressions can be used to predict extremes from the mean value and total variance. The equations are as follows:

1) mean versus rms speeds:
   mean speed = 0.89 + 0.87 (rms speed)

2) mean versus 1% speed:
   1% speed = 1.20 + 2.67 (mean speed)

3) rms versus 1% speed:
   1% speed = 2.97 + 2.40 (rms speed)

In the above equations the speeds have been expressed in centimeters per second.

For convenience in later intercomparisons the following table gives values of the three parameters at intervals of total variance used elsewhere in this appendix.

Total Variance (cm2/s2)	rms speed (cm/s)	Estimated mean speed (cm/s)	Estimated 1% speed (cm/s)
25	5	5	15
50	7	7	20
100	10	10	27
200	14	13	37

6.3.2 Current strength in the ZSFs--

PSDDA placed current meter moorings at the existing disposal sites in Elliott Bay (Fourmile Rock) and Port Gardner. PSDDA also placed a mooring in the vicinity of the preferred site in Port Gardner. Table II.6-1 provides a summary of these current meter measurements.

The strength of currents in the ZSFs was calculated using the following parameters: 1) total variance computed from field observations taken, averaged over the entire water column; 2) 1% peak speed for current meters located within ten meters above

the bottom; 3) total variance computed from observations made using the hydraulic model for spring tide conditions; and 4) peak currents during the extreme spring tide of 12-13 December 1985 simulated using the WES numerical tidal model.

Maps of total variance were computed using data throughout the water column (Figs. II.6-12 - II.6-15). Although these records were obtained at varying times and depths, regional patterns are evident within some of the ZSFs. In the three bays (Port Gardner; Elliott Bay; and Commencement Bay) there are comparable patterns graduating from low variance (20-40 $cm^2\ s^{-2}$) to values typical of the more rapidly flowing mid-channel areas (in excess of 200 $cm^2\ s^{-2}$). Observations are not available within the Saratoga Passage ZSF, but two stations have been occupied immediately to the north and south of the ZSF. The variance at these sites ranges between 95-250 $cm^2\ s^{-2}$ (Fig. II.6-12).

Because the total variance may vary substantially with depth and because current speeds near the bottom are of prime importance to PSDDA, the 1% highest speeds were mapped where observations have been made within ten meters of the bottom (Fig. II.6-16). Unfortunately, there are very few measurements of this type except in Elliott Bay. The 1% speeds vary from 17 centimeters per second in inner Elliott Bay, to 25 centimeters per second at Fourmile Rock, to 35 centimeters per second near mid-channel.

To interpolate between the sparse field data, regional patterns of the current speeds were developed from the numerical and hydraulic models. Figures II.6-17 - II.6-20 show the fastest speeds in the four ZSF areas obtained from the simulation of the extreme spring tide of 12-13 December, 1985. The peak speeds determined for each grid cell were contoured in the vicinity of the ZSFs in Saratoga Passage, Port Gardner, Elliott Bay, and Commencement Bay. It should be remembered that these values represent vertically averaged speeds so that fluctuations with depth have been suppressed.

The patterns of the speed contours from the numerical model resemble those of variance in Elliott and Commencement Bays obtained from the field data, and they provide resolution to the patterns in Port Gardner and Saratoga Passage (Figs. II.6-17 and II.6-18). In Saratoga Passage the extreme speeds generally lie in excess of 15-20 centimeters per second in the vicinity of the ZSF (Fig. II.6-17). In Port Gardner there appears to be a zone of lower currents southeast of Gedney Island where extreme speeds are less than 10 centimeters per second (Fig. II.6-18).

Total variance was also computed from observations made near the water surface in the hydraulic model. Because tidal currents at depth were of interest, the variance was computed for spring tides and low runoff. In this way runoff effects would be minimal, and the tidal currents at depth would be most reflected in the variance maps and therefore more comparable to

the results of the numerical model which doesn't include runoff effects. Observations were available for Elliott and Commencement Bays (Figs. II.6-21 and II.6-22) but, unfortunately, were not available for Port Gardner and Saratoga Passage. It can be seen that the patterns are similar to those for the numerical model and the field data. These similarities gave the DSWG some confidence that the numerical model could detect the transition between the quieter water in the bays and the stronger currents at mid-channel.

6.4. Prevailing Currents

The historical data were examined to determine possible pathways by which the suspended sediment may be carried by prevailing currents. For this purpose the current meter records previously examined for current strength were also used to compute the prevailing currents expressed mathematically as vectors having a net speed and direction. The computations were made in 60 meter depth intervals (Figs. II.6-23 - II.6-25). The following sections describe the prevailing currents in the ZSFs. Section II.7 describes the estimated amount of dredged material transported by the prevailing currents.

6.4.1 Saratoga Passage--

The vertical distribution of the net currents has been previously summarized by Barnes and Ebbesmeyer (1978) and Ebbesmeyer et al. (1986). Information is lacking to describe the horizontal patterns of the prevailing currents. At mid-channel the vertical distribution (Fig. II.6-26) may be described as follows. The surface layer contains a large amount of Skagit River water extending between approximately 0-10 meters, and flows southward along the mean axis of Saratoga Passage. Beneath the surface layer the prevailing flow runs counter to the surface flow northward along Saratoga Passage.

Dredged material which remains suspended in the water column will thus be transported in two major directions. Material remaining in the upper layer will be quickly transported southward at the rate of approximately 0-5 miles per day depending on the depth where material becomes suspended. The most rapid flow occurs near the water surface, and slow outflow occurs where the prevailing current changes direction between the northward and southward prevailing flows. Material remaining suspended in the deeper, inflowing layer will travel northward in Saratoga Passage at a rate of approximately 0-1 mile per day. Therefore, because of the opposing flow directions of the two layers, it is possible that suspended material will be dispersed over a distance of several tens of miles after several days.

6.4.2 Port Gardner--

The prevailing flow in Port Gardner must merge with the two flow layers found in Saratoga Passage. However, few data records are available with which to construct these patterns. Figure II.6-27 contains hypothetical flow patterns inferred from the available data and locations of major rivers.

In the shallow surface layer, on the order of 10 meters (30 feet) deep, the discharge from the Stillaguamish and Snohomish Rivers generally flow southward so as to merge with the shallow outflow from Saratoga Passage (Fig. II.6-27). Based on the available data the prevailing direction of surface and midwater current in central Port Gardner is toward the southwest.

The deeper layer originates offshore of Mukilteo and separates into two branches: the main branch continues northward into Saratoga Passage, and a minor, weak branch diverges eastward into Port Gardner. The flow continues counterclockwise following the bottom contours around Port Gardner. The prevailing flow in central Port Gardner is therefore estimated to be northward and westward.

6.4.3 Elliott Bay--

Elliott Bay adjoins Puget Sound's Main Basin. At mid-channel in the Main Basin the prevailing flow (Fig. II.6-28) is generally northward at depths shallower than approximately 60 meters, and southward at greater depth. As one approaches Elliott Bay from mid-channel the prevailing flows generally become weaker and more variable in direction. This summary has been adapted from reports by Hinchey et al. (1980) and by URS and Evans-Hamilton, Inc. (1980).

The surface layer, containing a substantial amount of freshwater from the Duwamish River, flows northward along the Seattle waterfront in the depth range of approximately 0-5 meters (0-16 feet). At greater depth the prevailing flows are weak and erratic, but on average they appear to flow toward the head of Elliott Bay.

In the vicinity of the inner Elliott Bay ZSF the flow will generally be northward in the upper five meters because of the Duwamish River, and at greater depth water flows slowly toward the Duwamish River. In the vicinity of the Four Mile Rock ZSF the upper five meters of water generally continue toward the north. At greater depth there appears to be a northward flow that merges with the prevailing flow located toward mid-channel.

6.4.4 Commencement Bay--

In the approaches to Commencement Bay near mid-channel the prevailing flow (Fig. II.6-29) is generally westward from the water surface to bottom (Ebbesmeyer et al., 1984). A shallow surface layer contains a substantial amount of Puyallup River water. This layer generally flows out of Commencement Bay and merges with the westward flow. At greater depths there are two branches to the flow pattern. The major branch continues to the west feeding into The Narrows. The minor branch turns counter-clockwise and enters Commencement Bay. The available data suggest that there are eddy-like prevailing flows within the Bay (Ebbesmeyer et al., 1986).

Therefore in the portion of the ZSF located in outer Commencement Bay the prevailing flows are westward in the shallow surface layer and southward at greater depth.

Table II.6-1 PSDDA Current Meter Station Data for Port Gardner and Elliott Bay. (Source: EHI)

LOCATION	DEPTH (M)	NET SPEED (cm/s)	NET DIRECTION (°T)	TOTAL VARIANCE (cm^2/s^2)	MEAN SPEED (cm/s)	1% FASTEST SPEED (cm/s)	OBSERVATION BEGIN DATE	DURATION (Days)	LATITUDE (°N)	LONGITUDE (°W)
Port Gardner										
1	109.4	0.59	344	104.85	7.23	22.8	Oct 19, 1985	61	47-58.10	122-15.19
1	112.3	- -	- -	- -	5.51	15.9	Oct 19, 1985	61	47-58.10	122-15.19
2	65.1	3.47	241	64.00	7.16	26.2	Aug 22, 1986	30	47-58.06	122.16.10
2	118.4	- -	- -	- -	7.05	18.3	Aug 22, 1986	30	47-58.06	122.16.10
2	120.4	2.41	350	84.17	8.06	22.7	Aug 22, 1986	30	47-58.06	122.16.10
Elliott Bay-Fourmile Rock										
1	168.4	0.65	34	151.73	10.09	26.9	Nov 7, 1985	42	47-37.40	122-25.09
1	171.2	- -	- -	- -	8.75	23.0	Nov 7, 1985	42	47-37.40	122-25.09
2	80.1	2.65	6	43.73	6.97	16.8	Oct 18, 1985	19	47-37.60	122-25.23
2	157.4	1.06	321	54.81	8.37	22.3	Oct 18, 1985	19	47-37.60	122-25.23
2	160.4	1.14	305	50.92	7.47	18.8	Oct 18, 1985	19	47-37.60	122-25.23

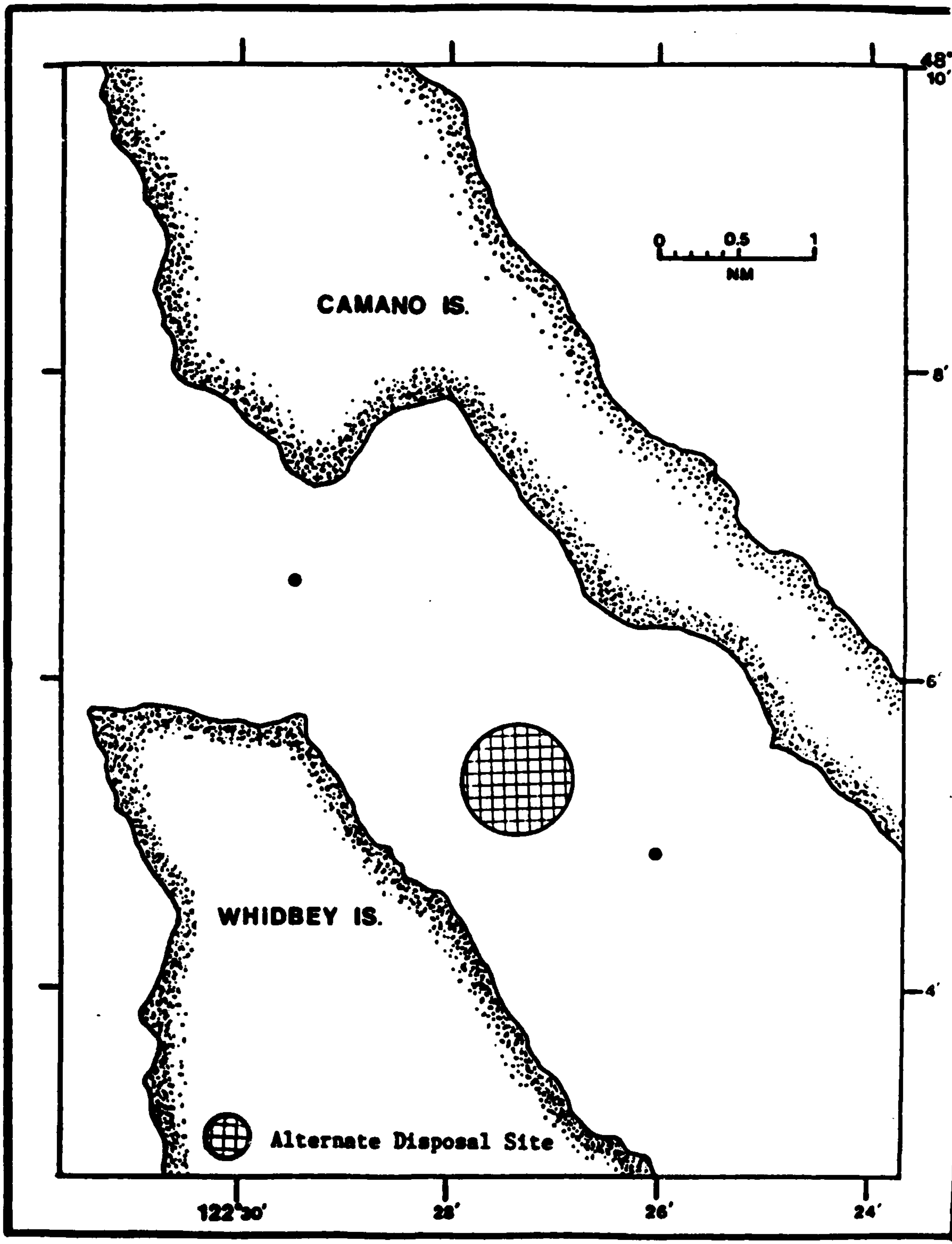


Figure II.6-1 Locations of current meter measurements (●) in the vicinity of the Saratoga Passage ZSF. (Source: EHI)

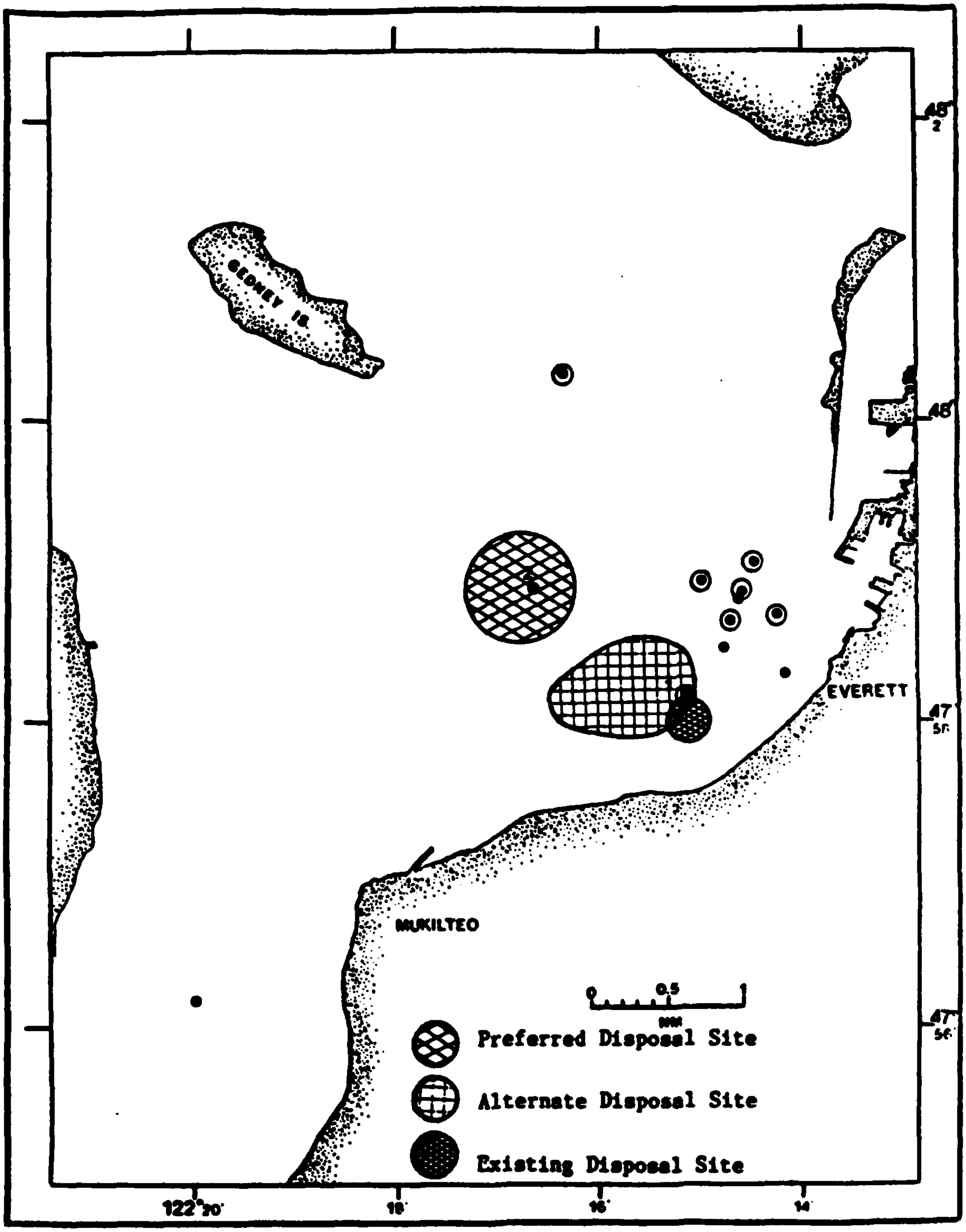


Figure II.6-2 Locations of current meter measurements (•) in the vicinity of the Port Gardner ZSF. Circled dots were used in various correlations of currents. The two PSDDA stations are denoted by 1 & 2. (Source: ENI)

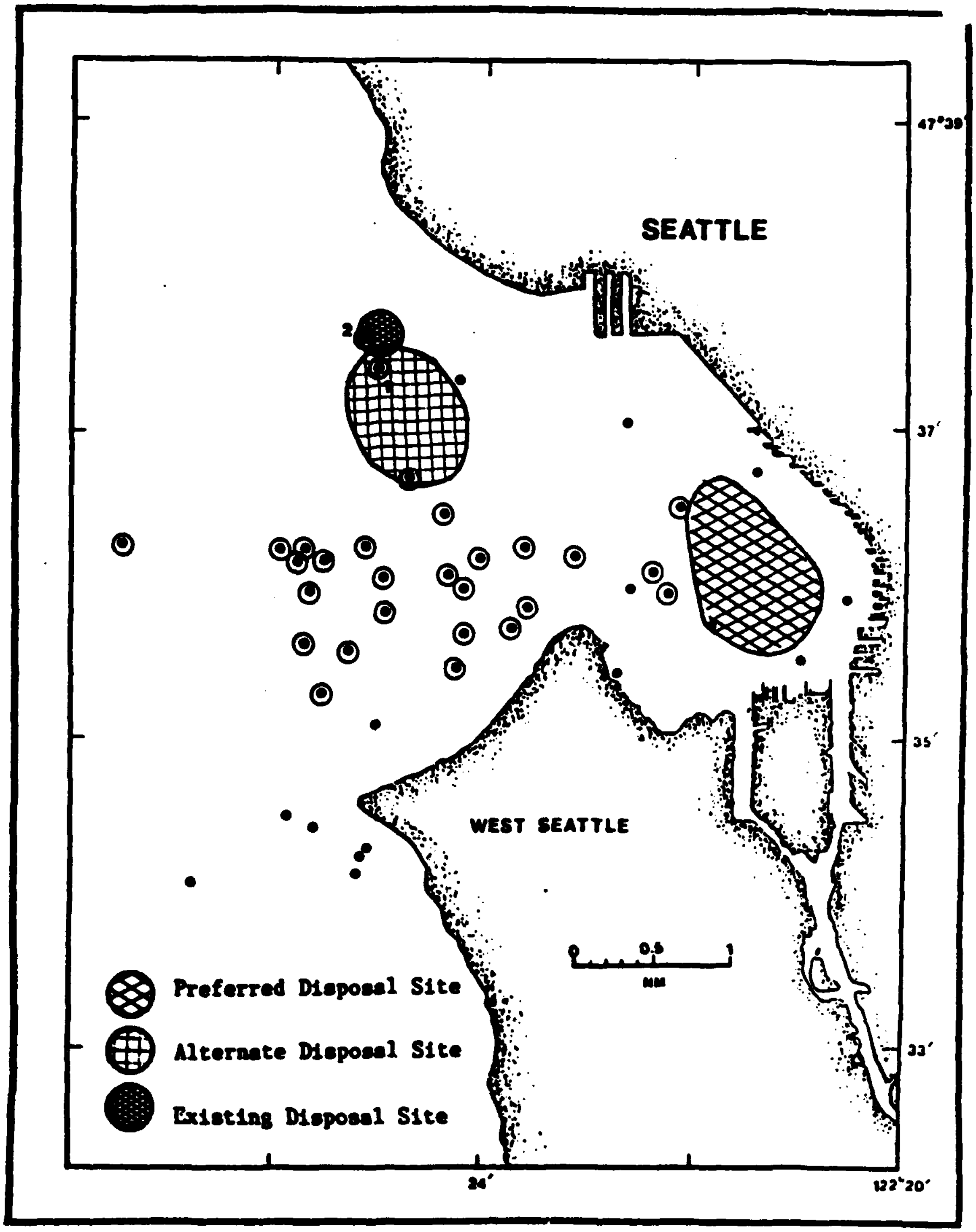


Figure II.6-3 Locations of current meter measurements (•) in the vicinity of the Elliott Bay ZSFs. Circled dots were used in various correlations of currents. The two PSDDA stations are denoted by 1 & 2. (Source: EHI)

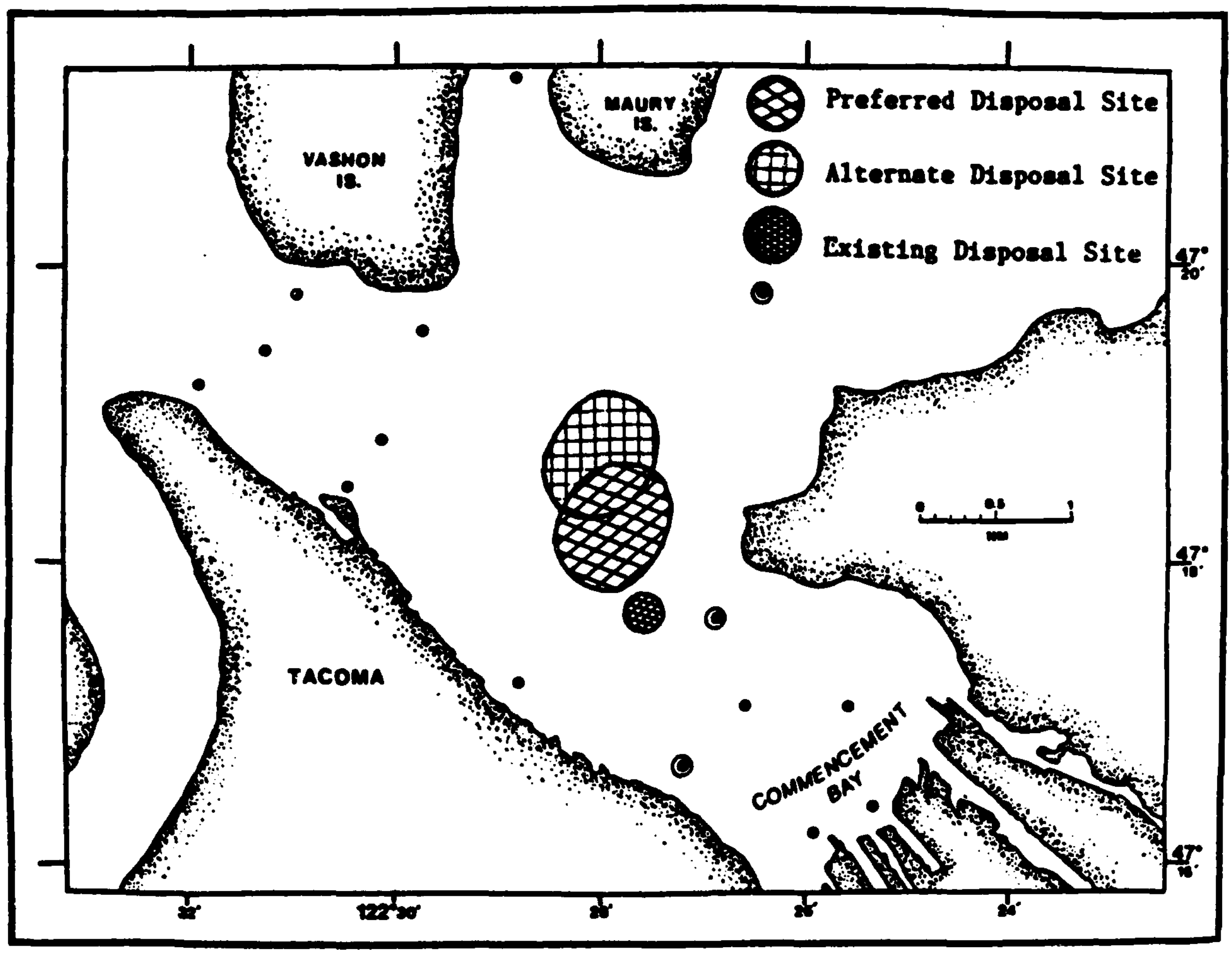


Figure II.6-4 Location of current measurements (•) in the vicinity of the Commencement Bay ZSF. Circled dots were used in various correlations of currents. (Source: EHI)

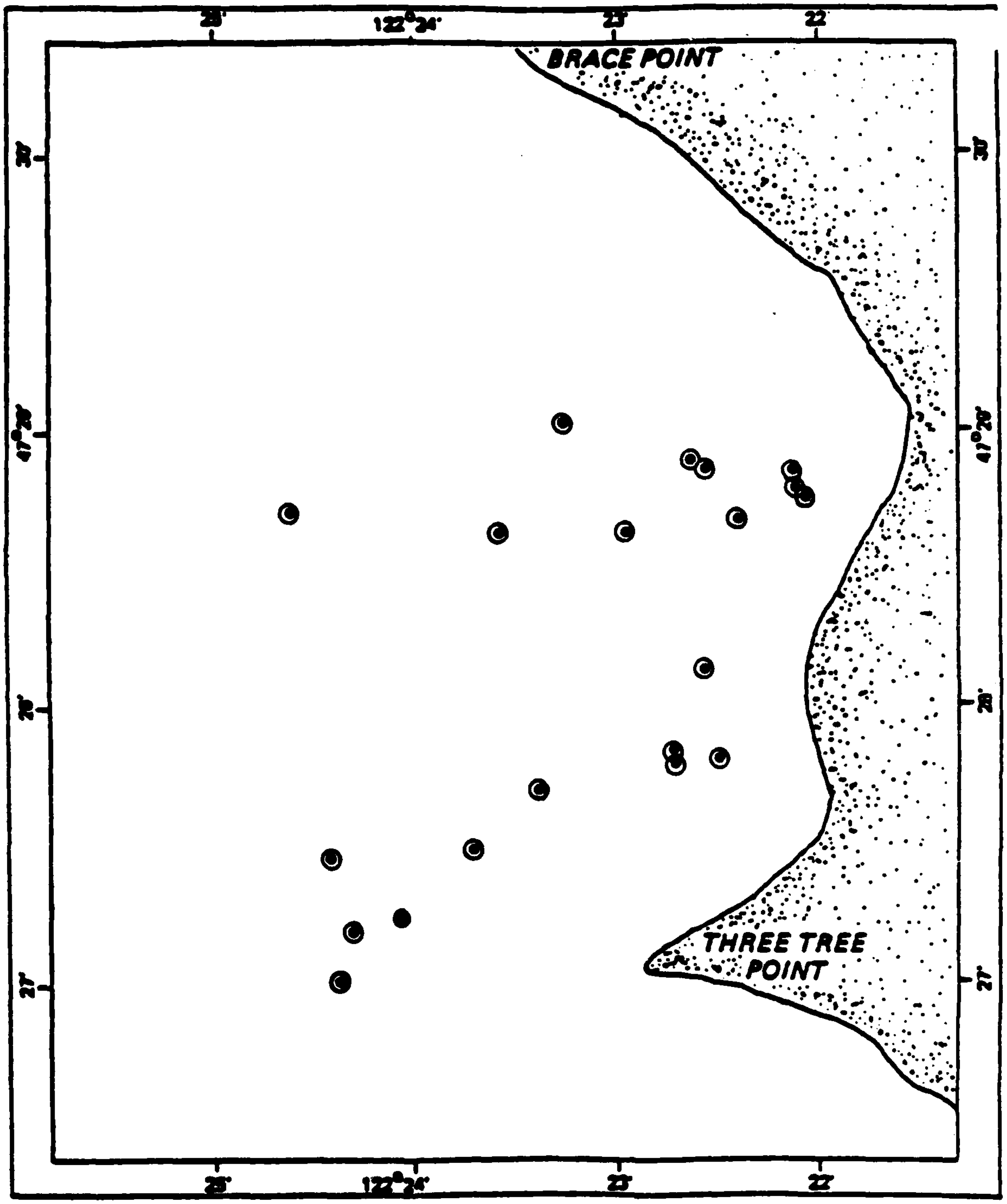
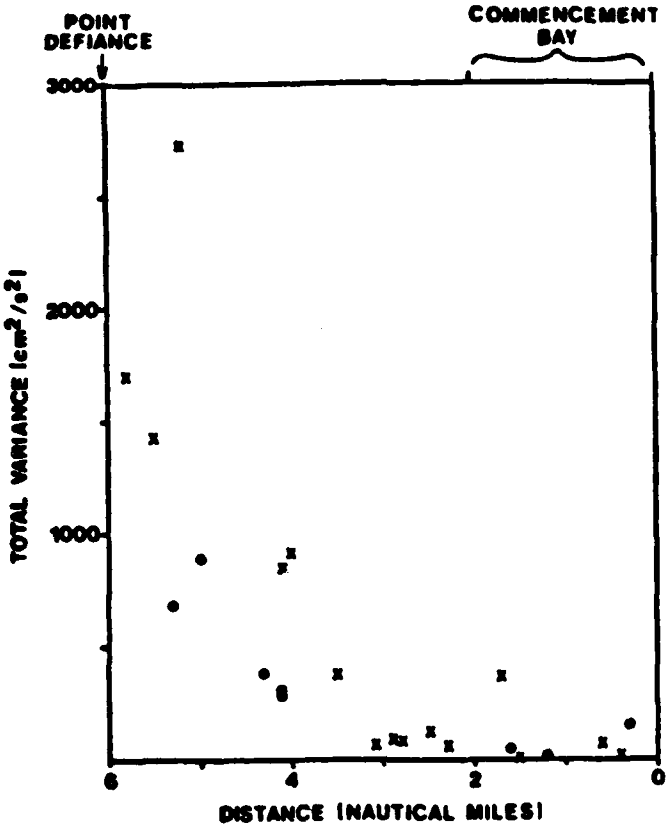


Figure II.6-5 Locations of current measurements in Seahurst Bay that were used in various current correlations. (Source: EHI)

A



B

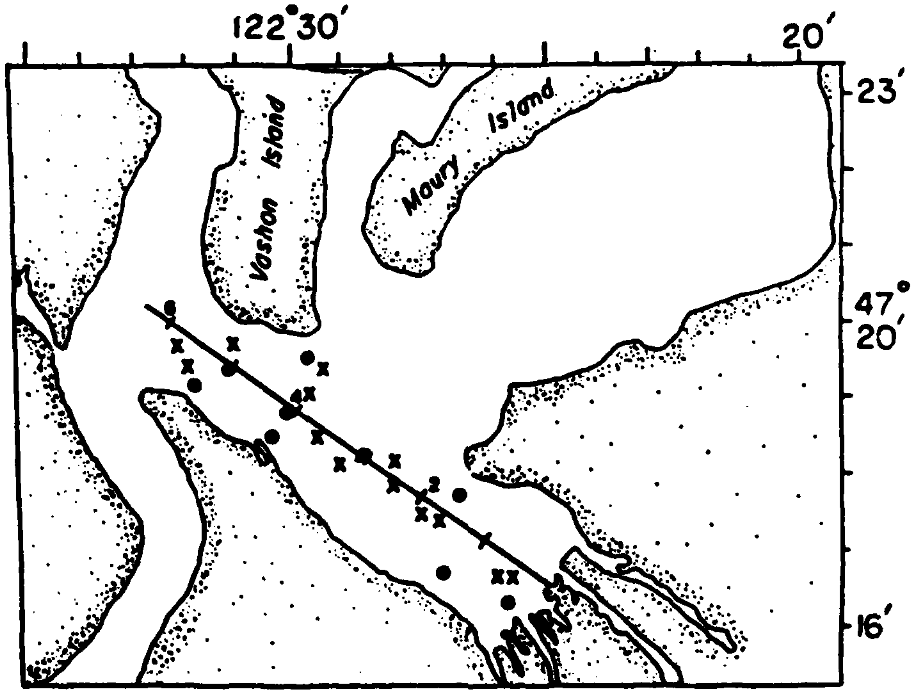


Figure II.6-6 Total variance from current measurements versus distance from the head of Commencement Bay. (a) Dots indicate field data and X's indicate model data. (b) Shows the observation sites and the scale indicates distance in nautical miles from the head of Commencement Bay. (Source: Ebbesmeyer et al., 1984).

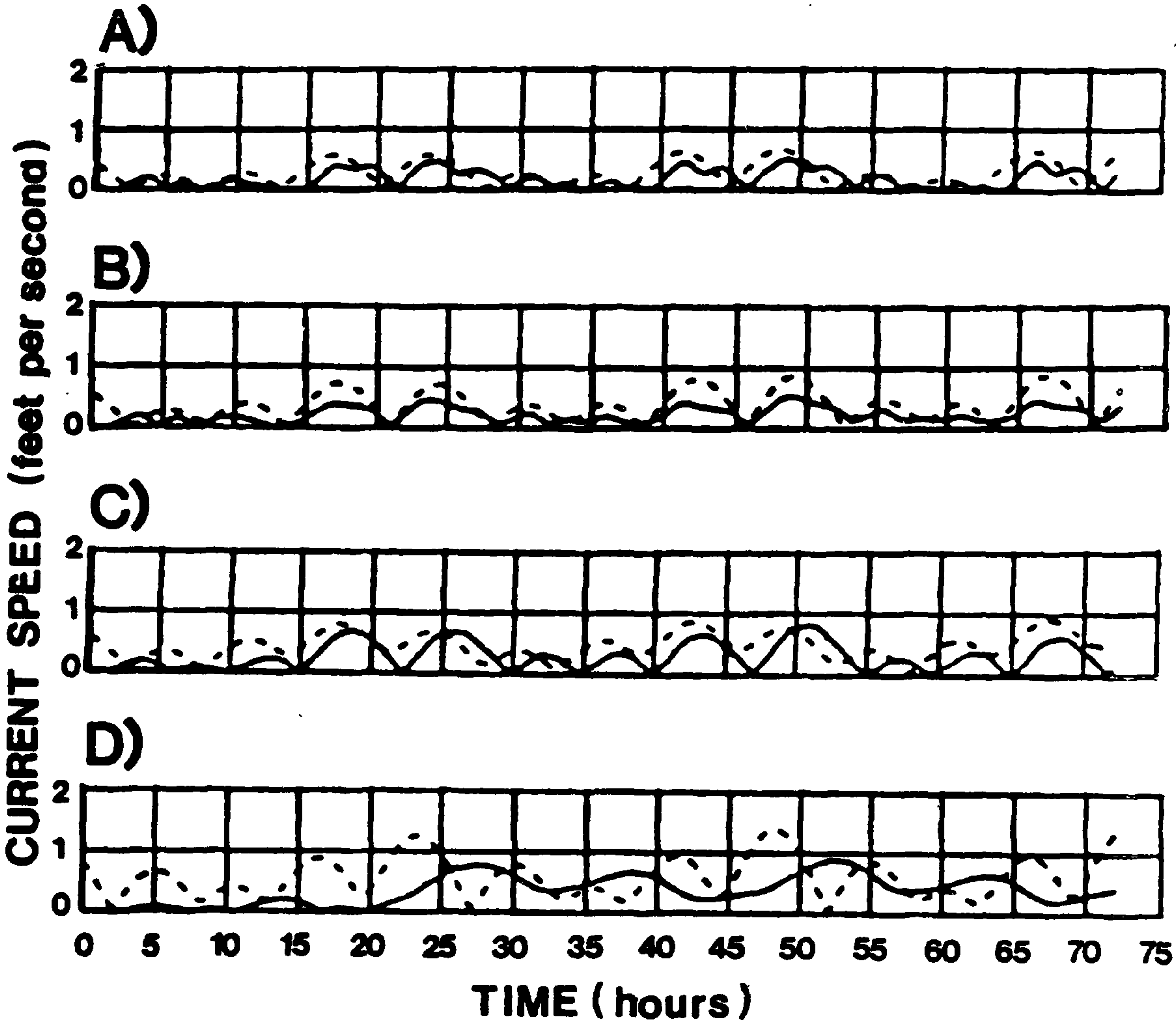


Figure II.6-7 Predictions from the numerical tidal model (dashed) versus observed (solid) tidal currents in the vicinity of: A) Saratoga Passage ZSF; B) Port Gardner ZSF; C) Elliott Bay ZSF; and D) Commencement Bay ZSF. See Figure II.6-8 for locations of A-D. (Source: EHI)

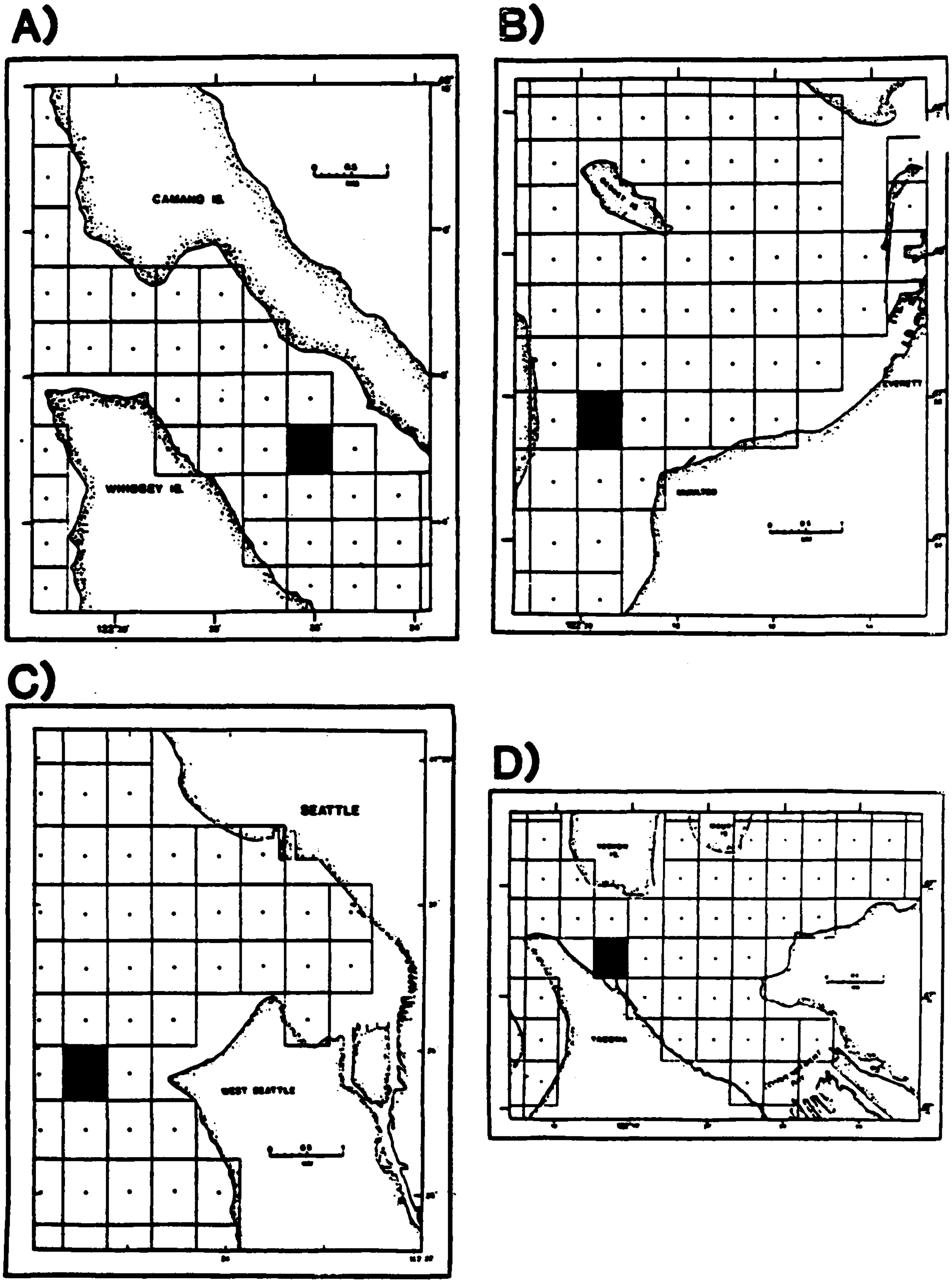


Figure II.6-8 Locations (darkened square) of intercomparisons between the numerical tidal current model and field observation. The other squares represent cells used in the model and data represent the centers of the squares. (Source: EHI)

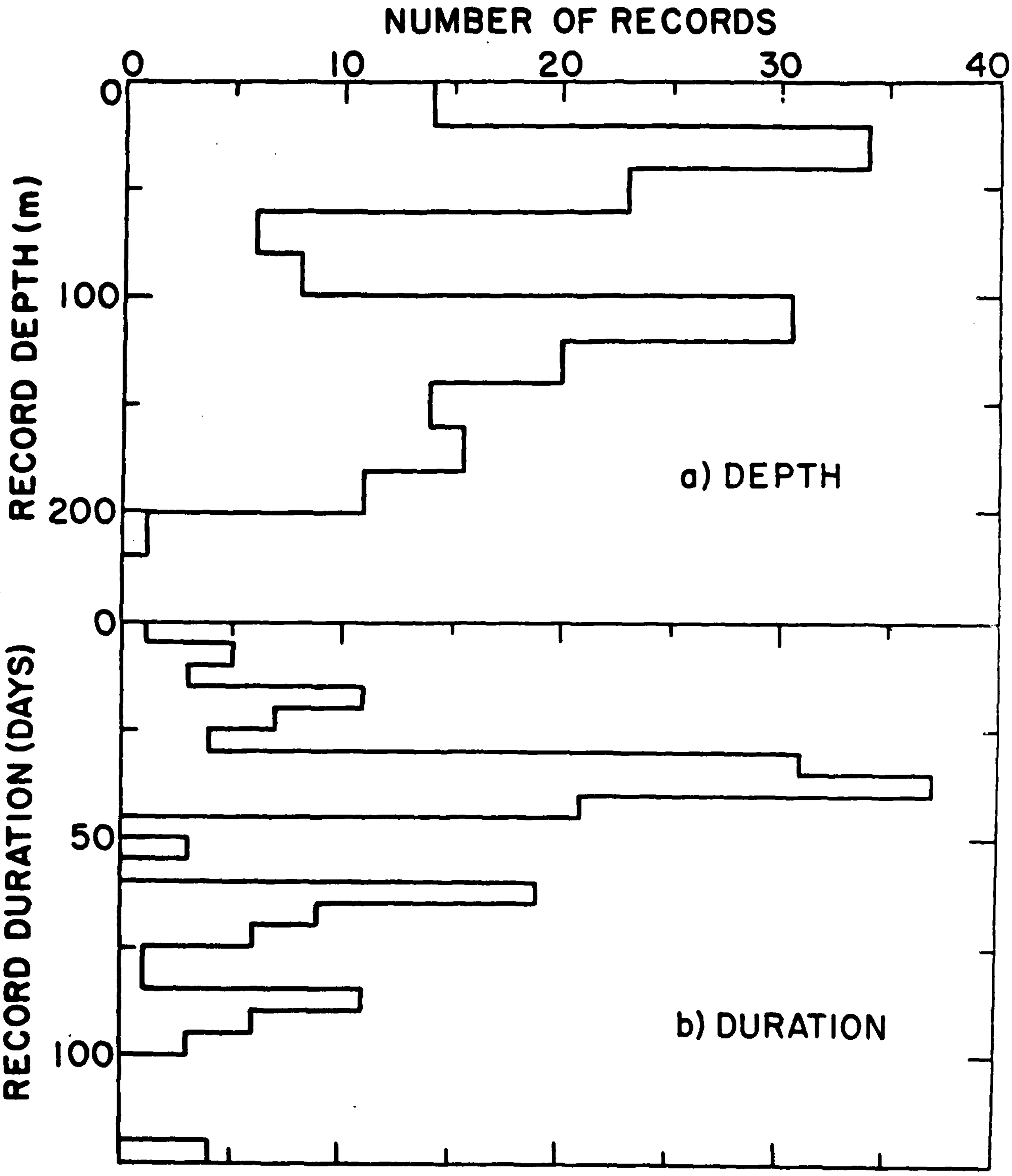


Figure II.6-9 Number of current meter records used in the correlation of current speed versus: a) depth; and b) duration. (Source: EHI)

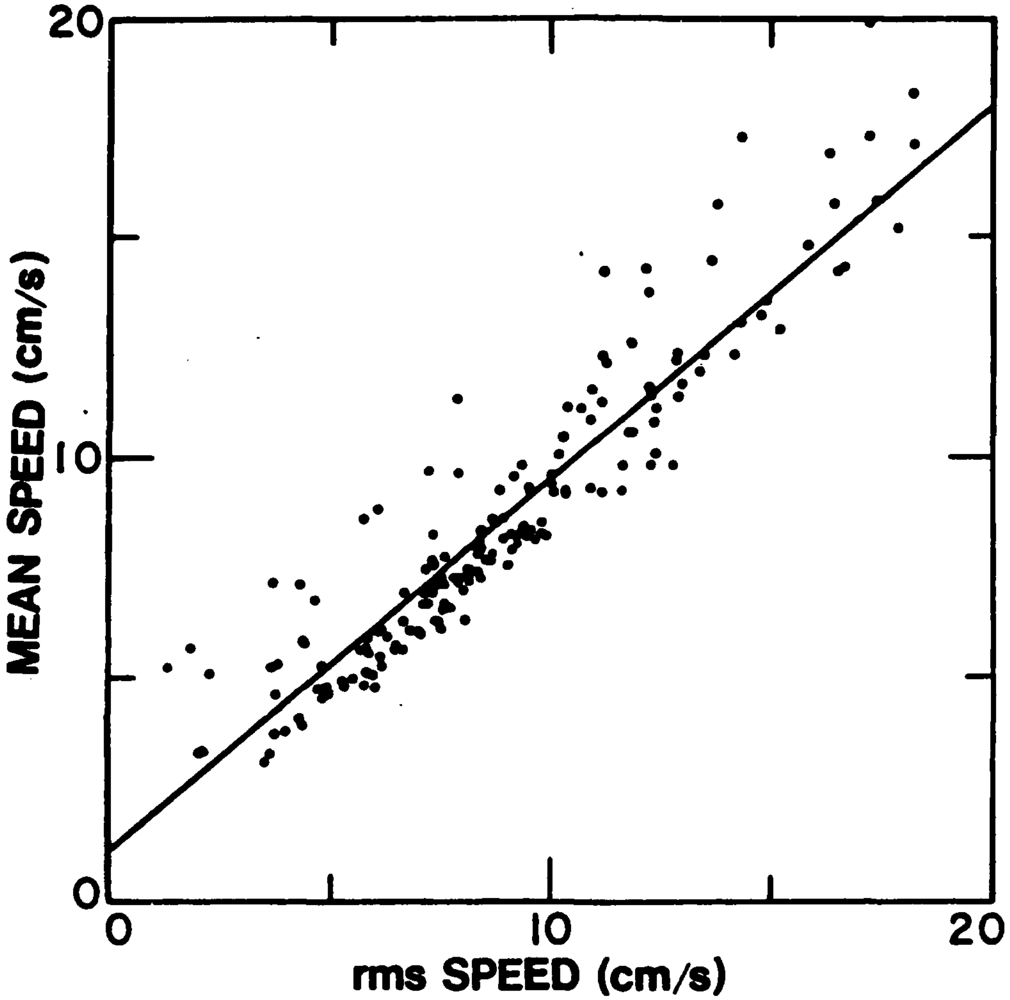


Figure II.6-10 Mean versus rms speed for 170 current meter records in Puget Sound. Each dot represents a current meter record. See Figures II.6-1 through II.6-5 for locations. The straight line represents the linear regression. (Source: EHI)

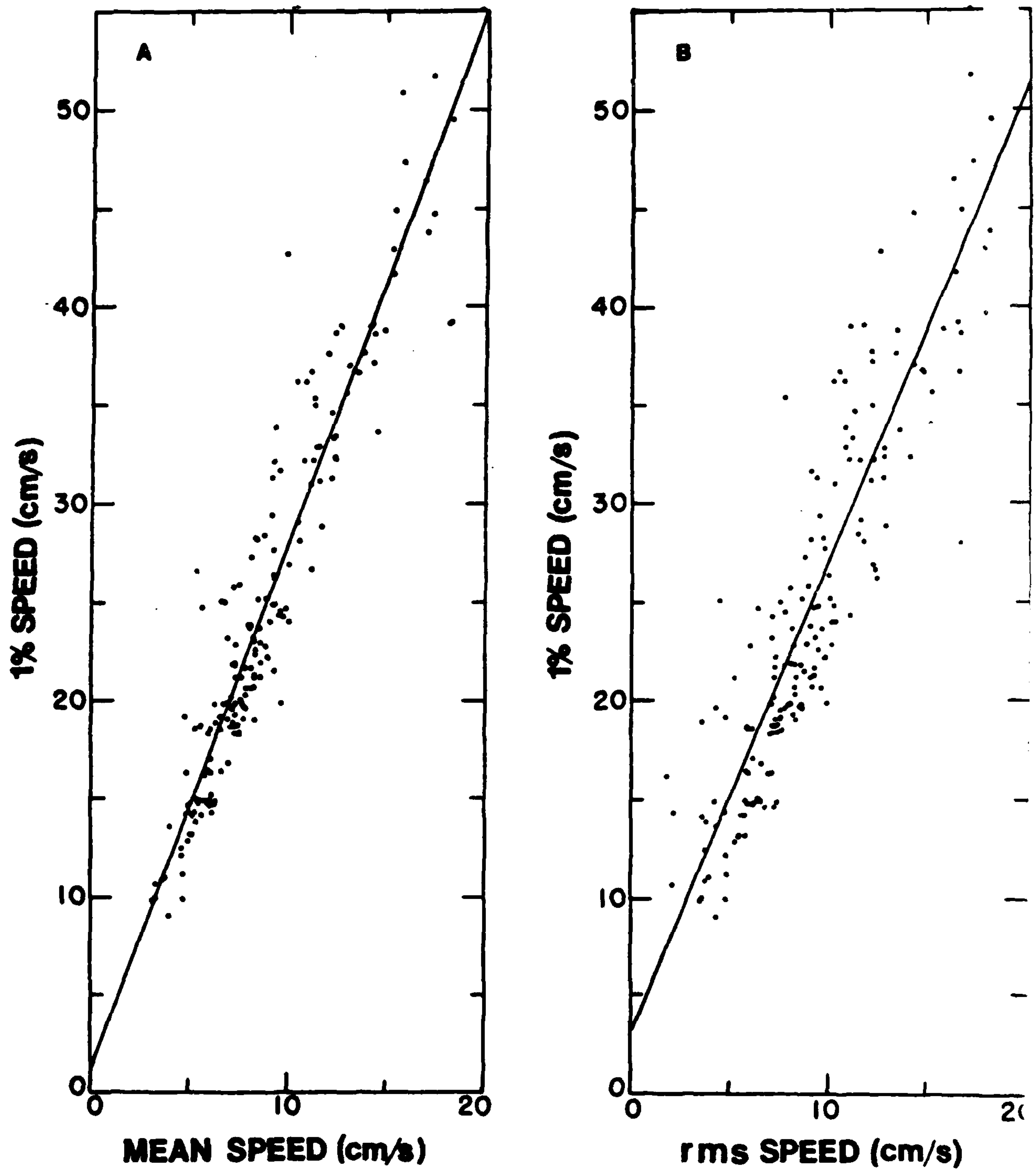


Figure II.6-11 The 1% speed versus (a) the mean speed and (b) rms speed. Each dot represents a current meter record, and the straight lines represent linear regression. (Source: EHI)

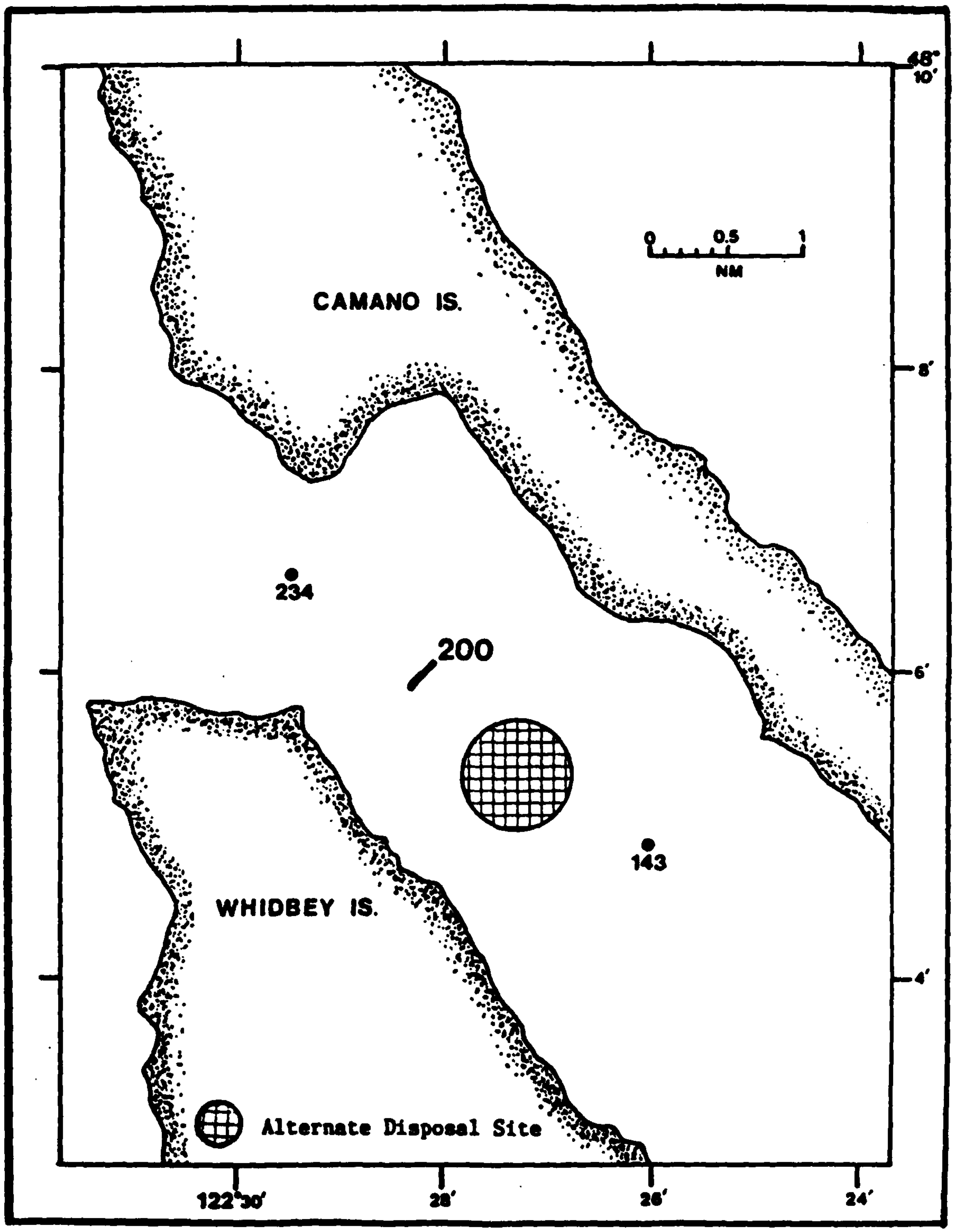


Figure II.6-12 Total variance in the vicinity of the Saratoga Passage ZSF. Numbers by dots indicate the total variance ($cm^2 s^{-2}$) as averaged over the water column. A contour of 200 $cm^2 s^{-2}$ is shown. (Source: EHI)

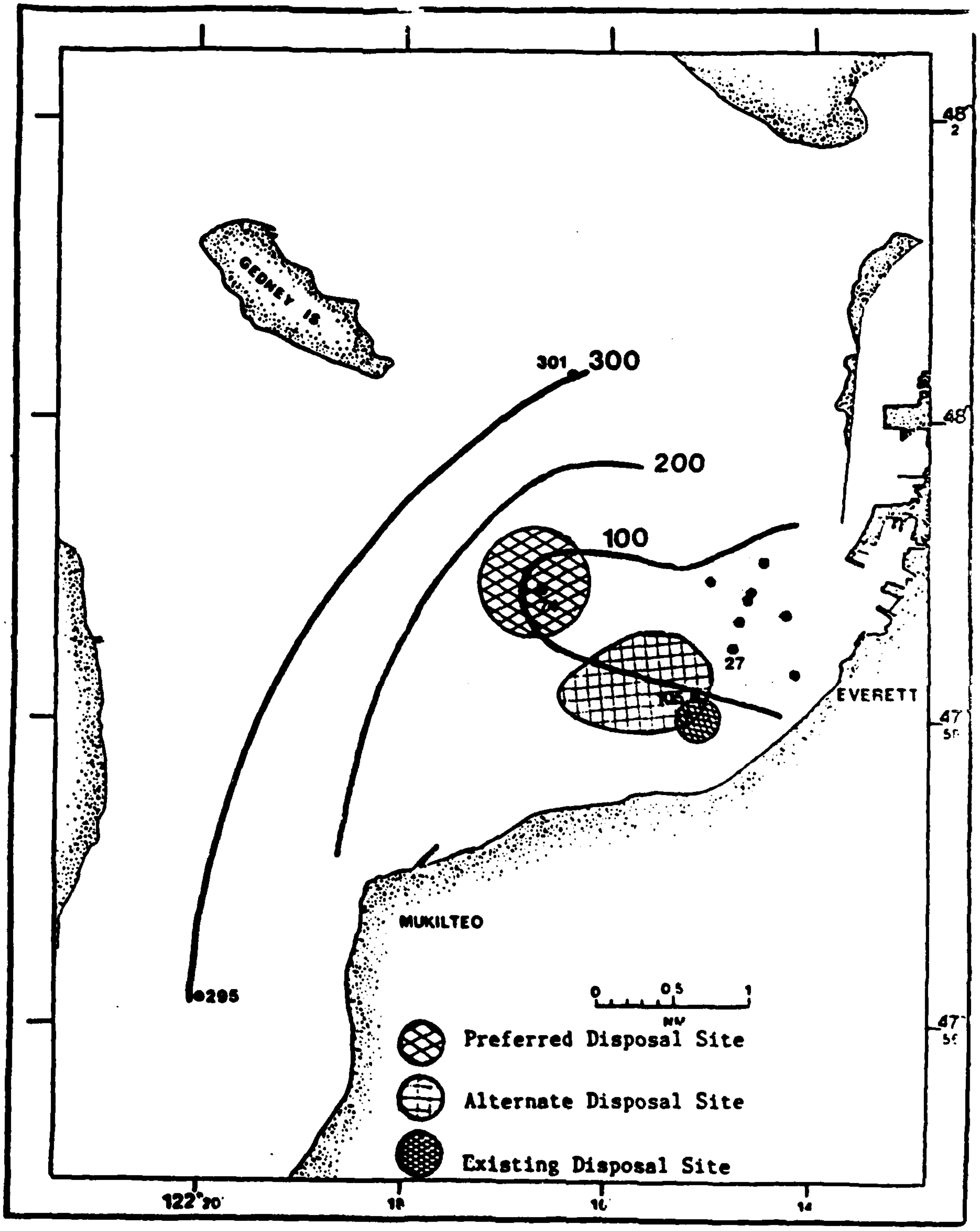


Figure II.6-13 Contour of total variance of the currents within the Port Gardner ZSF. Numbers by dots indicate total variance ($cm^2 s^{-2}$) as averaged over the water column. (Source: EHI)

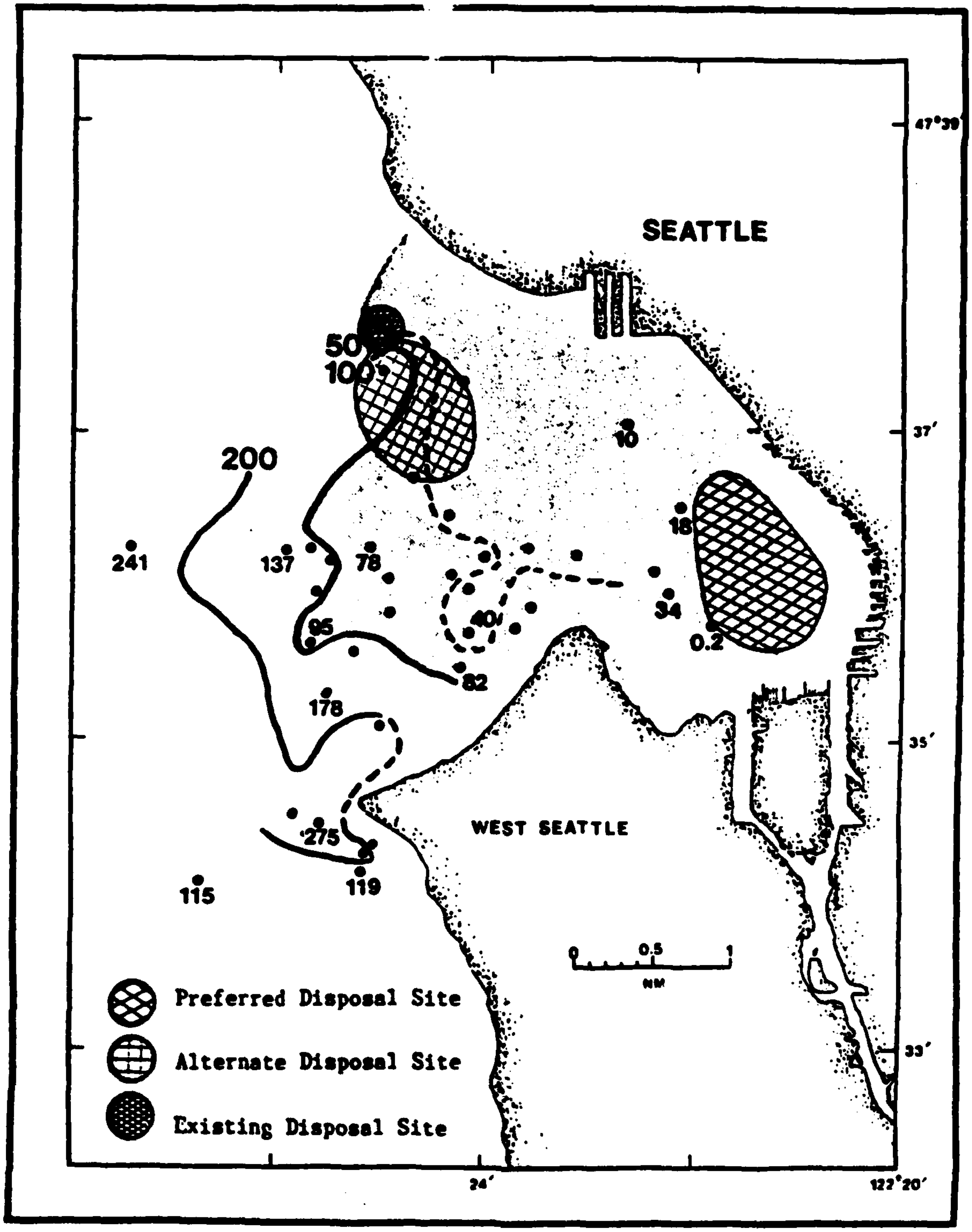


Figure II.6-14 Contour of total variance of the currents in the vicinity of the Elliott Bay ZSFs. The number by the dots indicate total variance of the currents (cm^2s^{-2}) averaged over the water column. (Source: EHI)

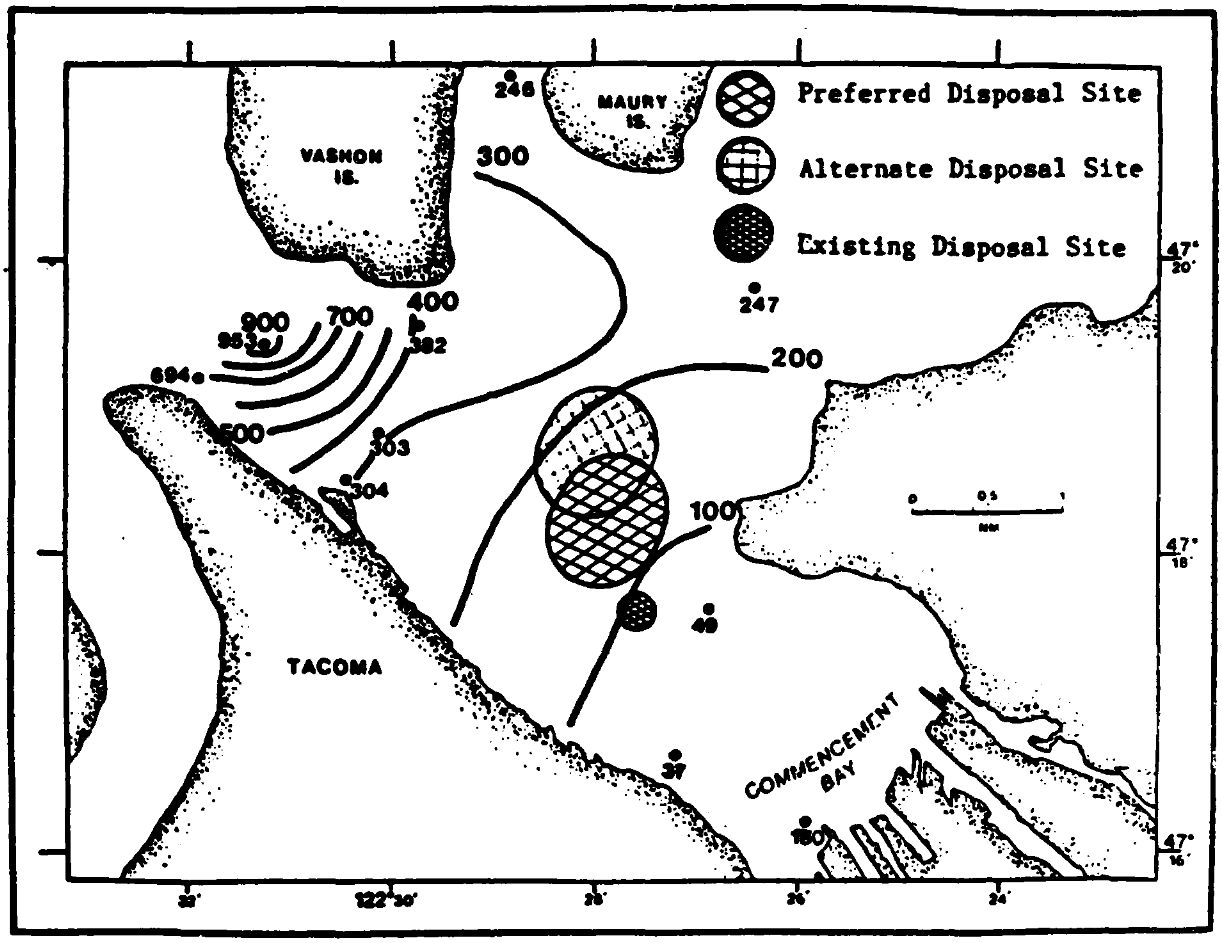


Figure II.6-15 Contour of total variance of the currents in the vicinity of the Commencement Bay ZSF. Number by dots indicate total variance of the currents (cm^2s^{-2}) averaged over the water column. (Source: EHI)

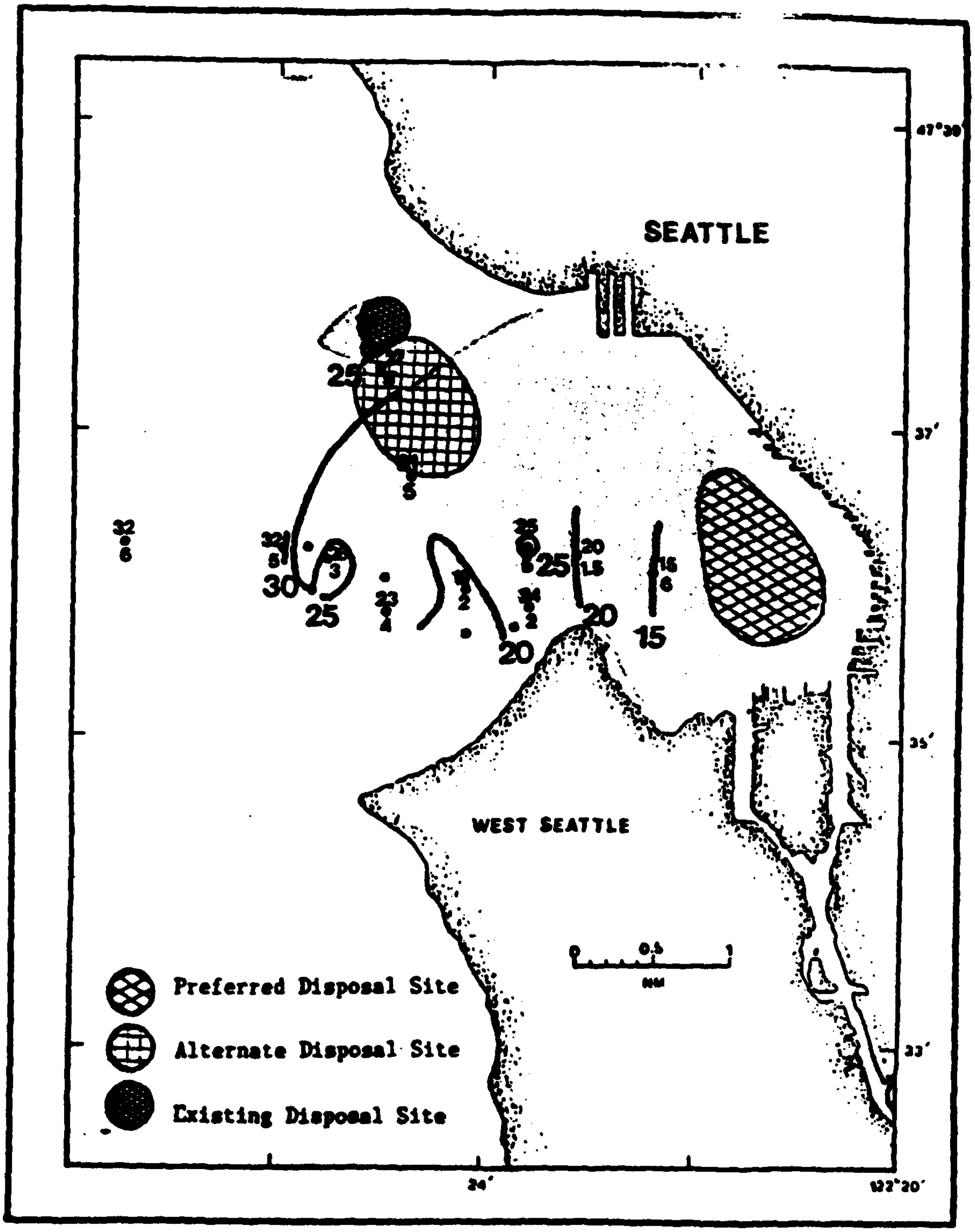


Figure II.6-16 Measurements of the 1% fastest current speed within 10 meters above the bottom. Number above the dots indicate total variance of the currents ($cm^2 s^{-2}$), and numbers below dots indicate the distance above bottom. (Source: EHI)

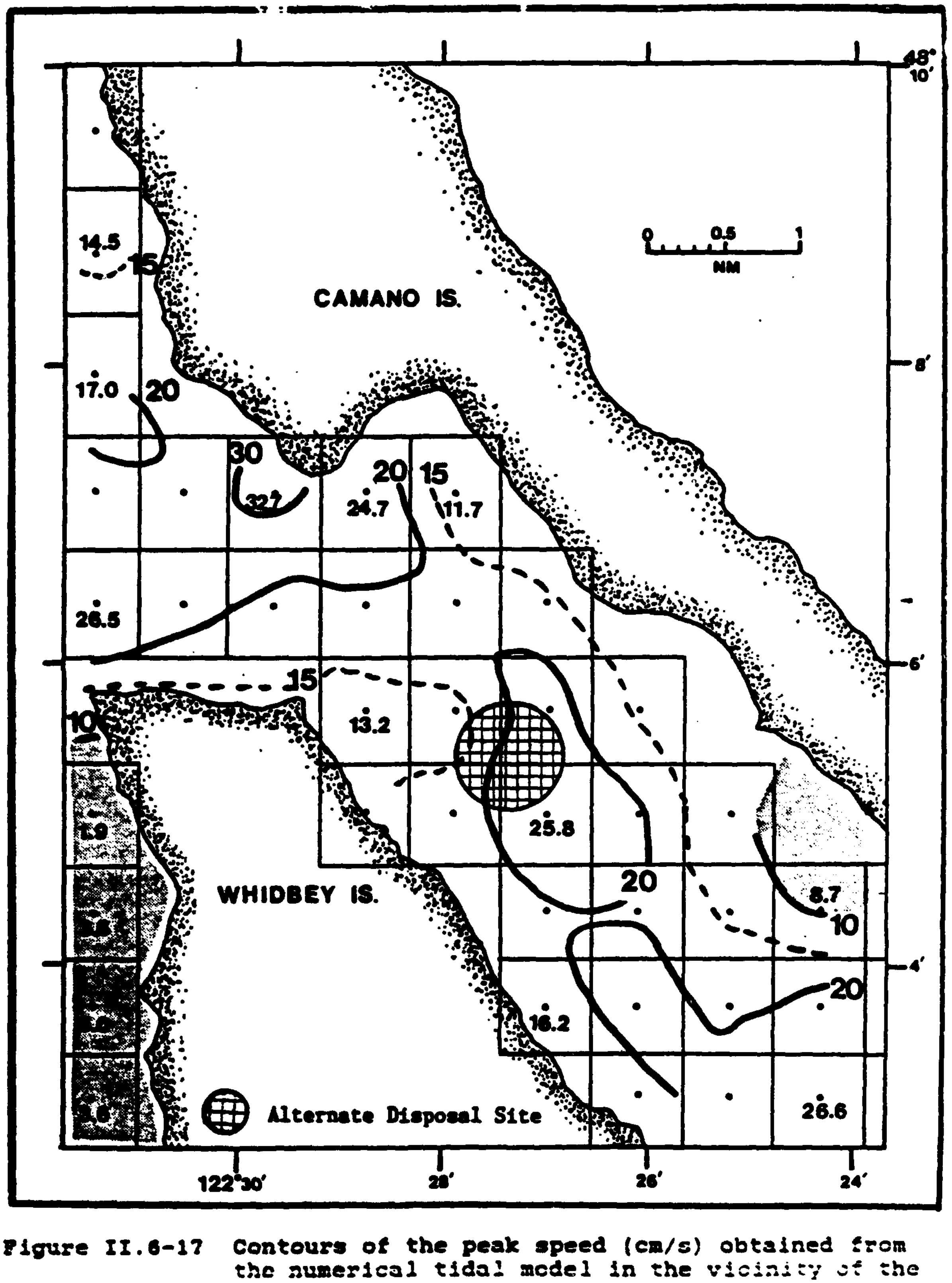


Figure II.6-17 Contours of the peak speed (cm/s) obtained from the numerical tidal model in the vicinity of the Saratoga Passage ZSF for the extreme spring tides of Dec. 12-13, 1985. The squares represent grid cells and numbers by the center of selected cells (dots) indicate selected peak speeds. (Source: EHI)

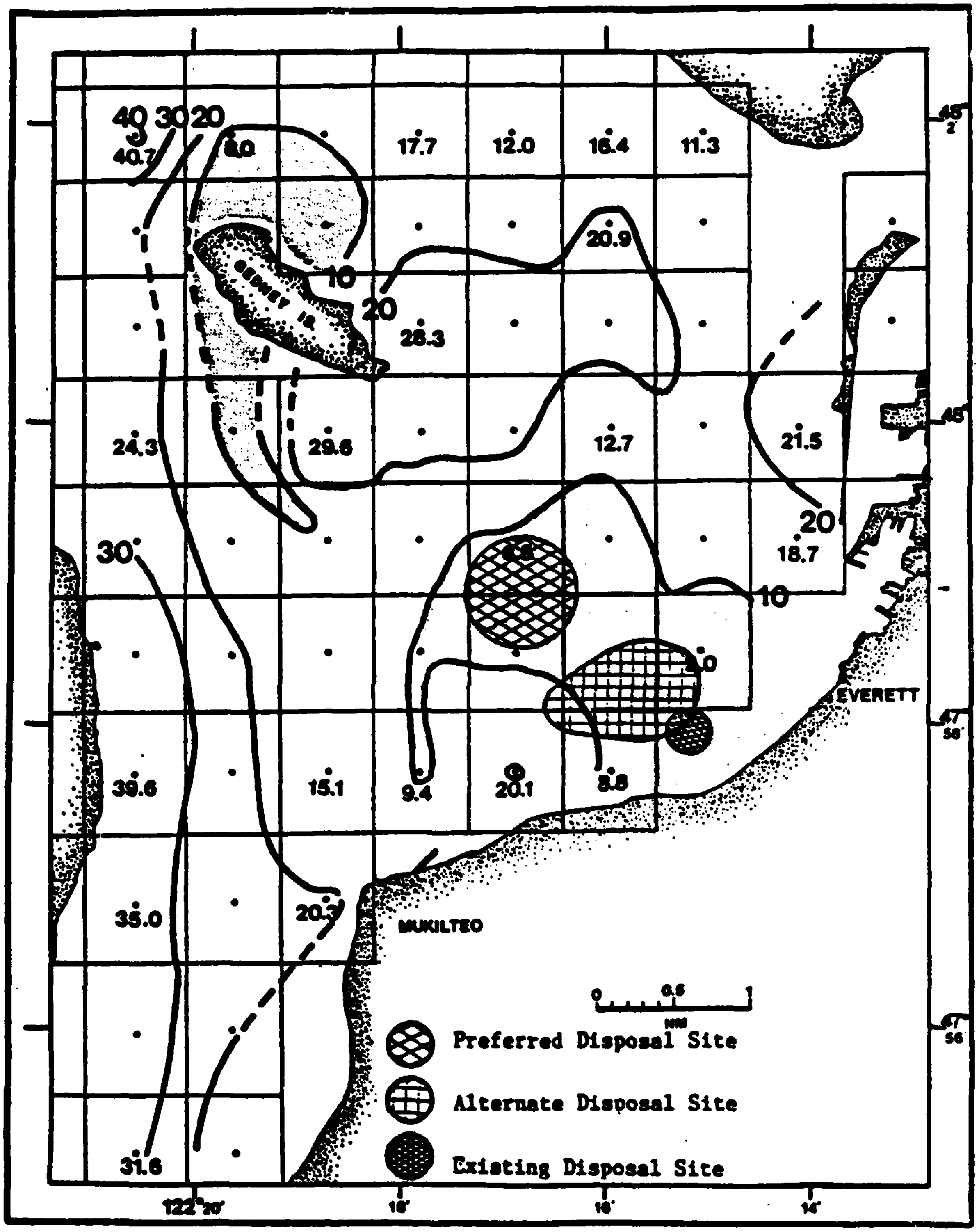


Figure II.6-18 Contours of the peak speed (cm/s) obtained from the numerical tidal model in the vicinity of the Port Gardner ZSF for the extreme spring tides of Dec. 12-13, 1985. The squares represent grid cells and numbers by the center of selected cells (dots) indicate selected peak speeds. (Source: EHI)

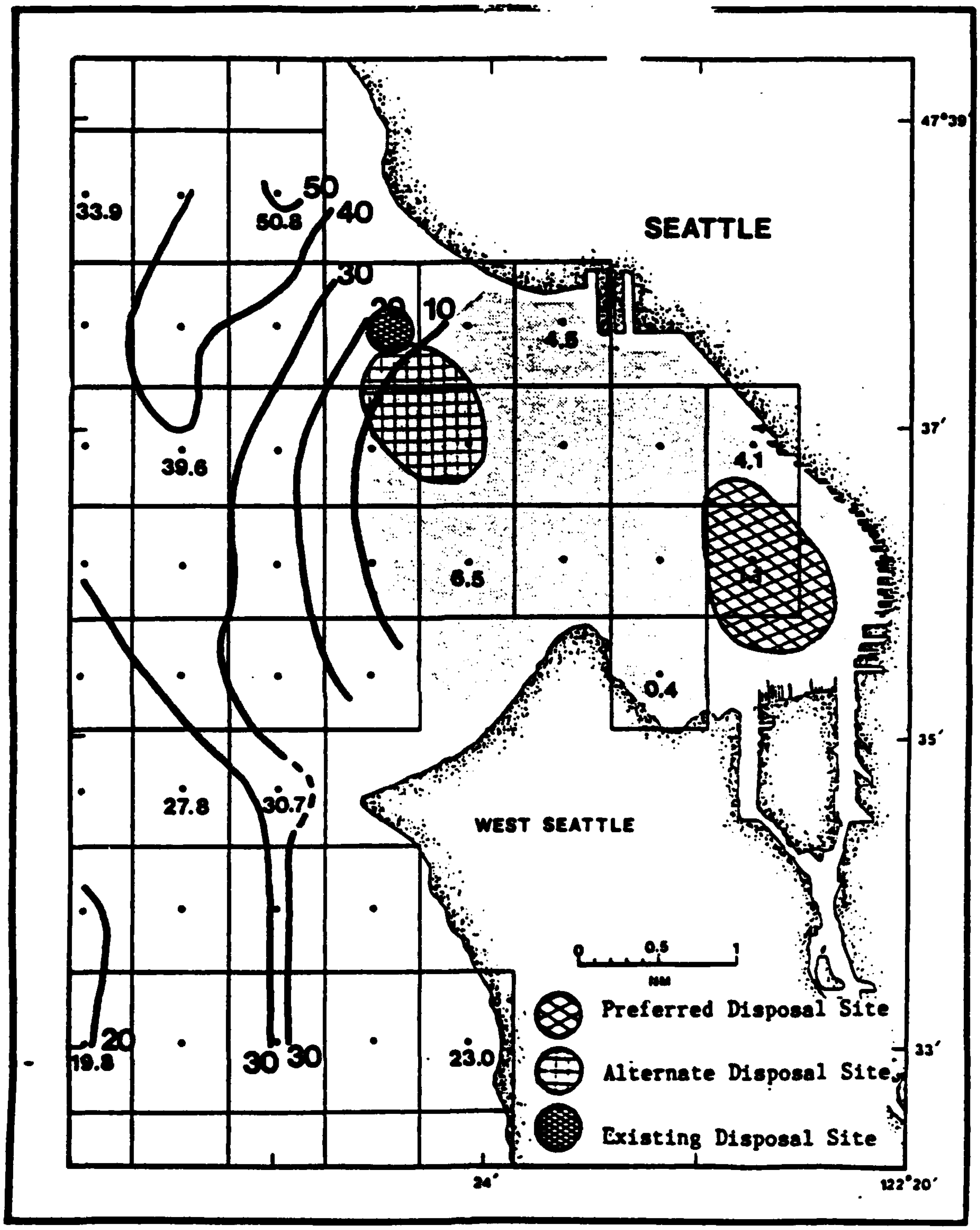


Figure II.6-19 Contours of the peak speed (cm/s) obtained from the numerical tidal model in the vicinity of the Elliott Bay ZSFs for the extreme spring tides of Dec. 12-13 1985. The squares represent grid cells and numbers by the center of selected cells (dots) indicate selected peak speeds. (Source: EHI)

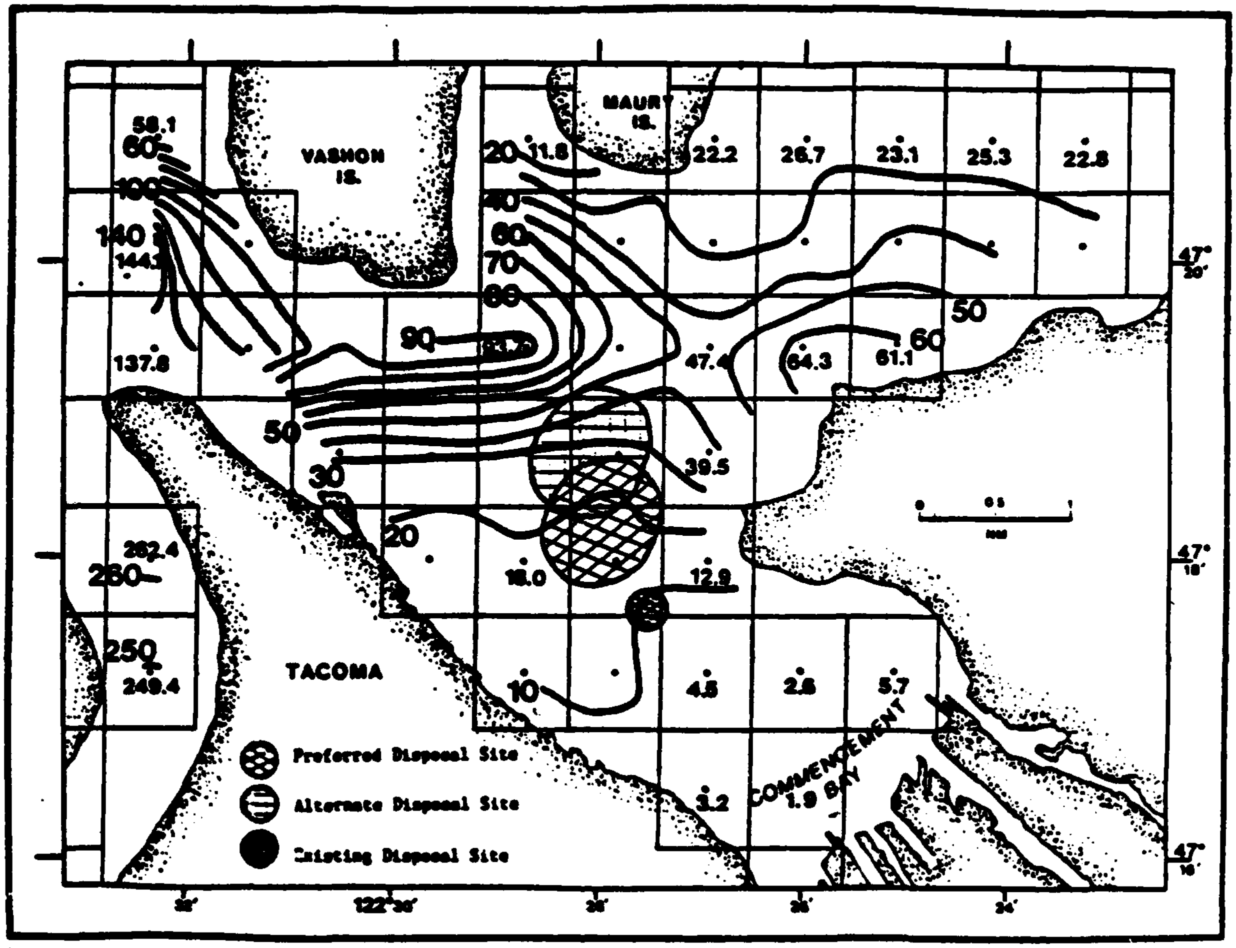


Figure II.6-20 Contours of the peak speed (cm/s) obtained from the numerical tidal model in the vicinity of the Commencement Bay ZSF for the extreme spring tides of Dec. 12-13, 1985. The squares represent grid cells and numbers by the center of selected cells (dots) indicate selected peak speeds. (Source: EHI)

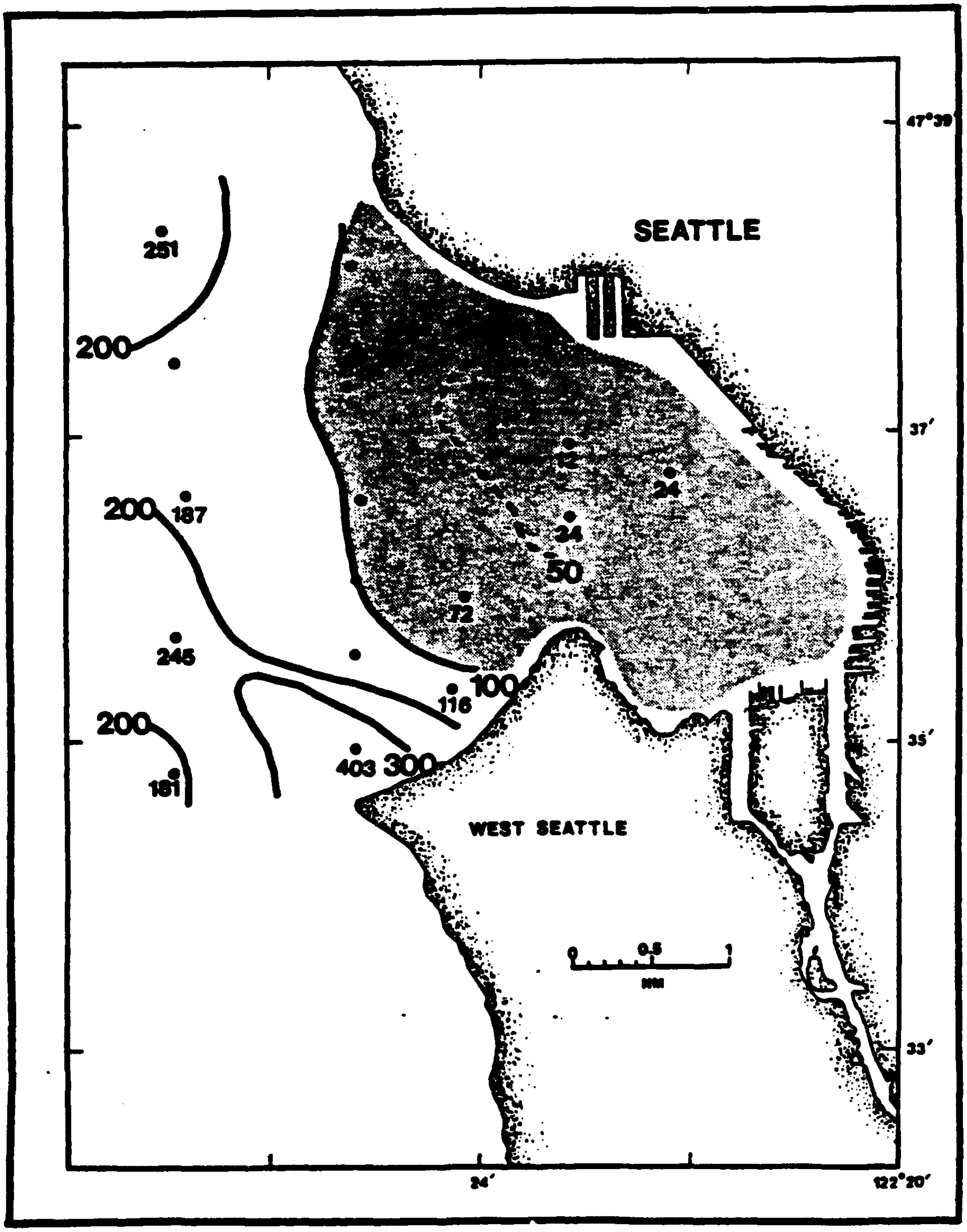


Figure II.6-21 Contours of total variance of the currents computed at the water surface in the hydraulic model in Elliott Bay for spring tide and low runoff conditions. Dots indicate locations of measurements and number indicates total variance of the currents (cm^2s^{-2}). (Source: EHI)

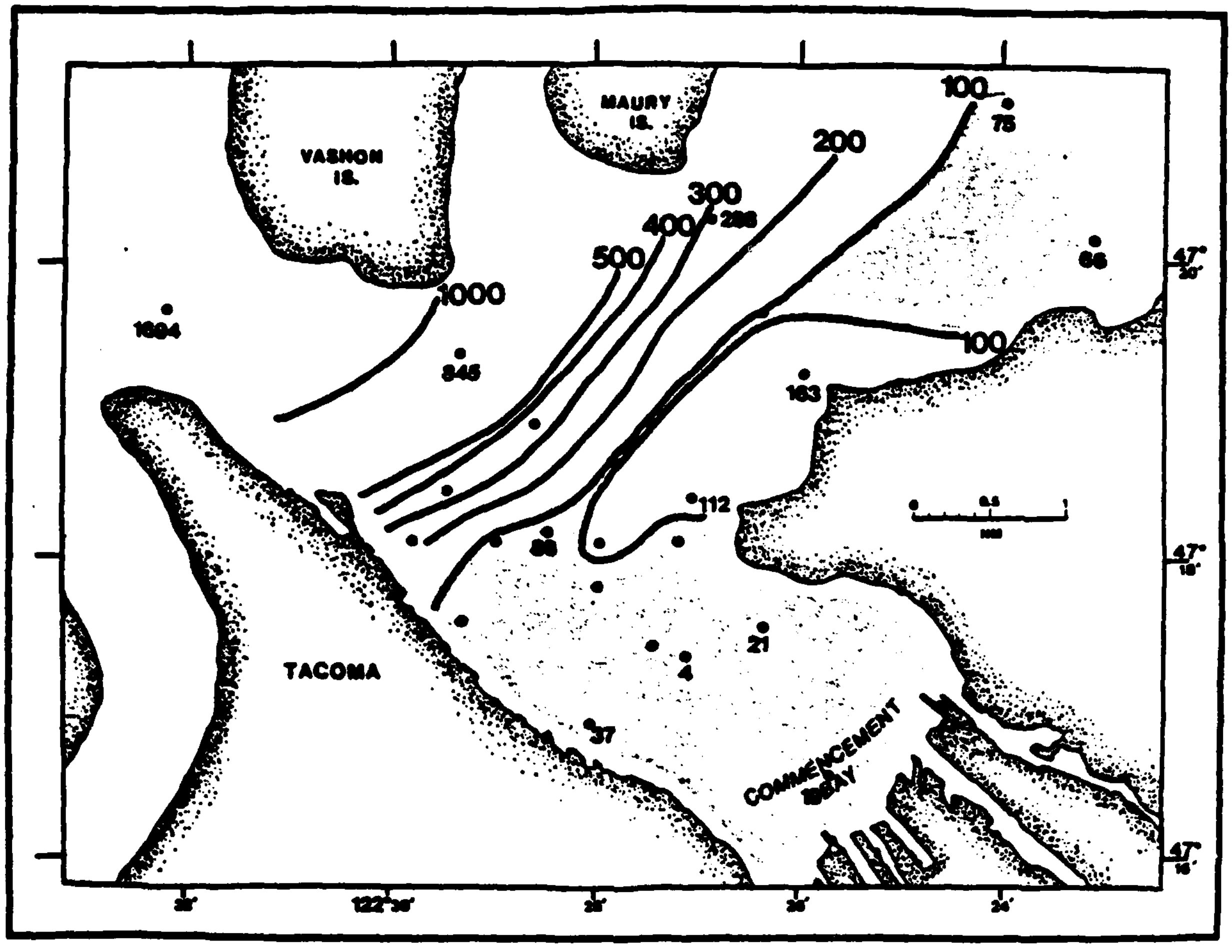


Figure II.6-22 Contours of total variance of the currents computed at the water surface in the hydraulic model in Commencement Bay for spring tide and low runoff conditions. Dots indicate locations of measurements and number indicates total variance of the currents ($cm^2 s^{-2}$). (Source: EHI)

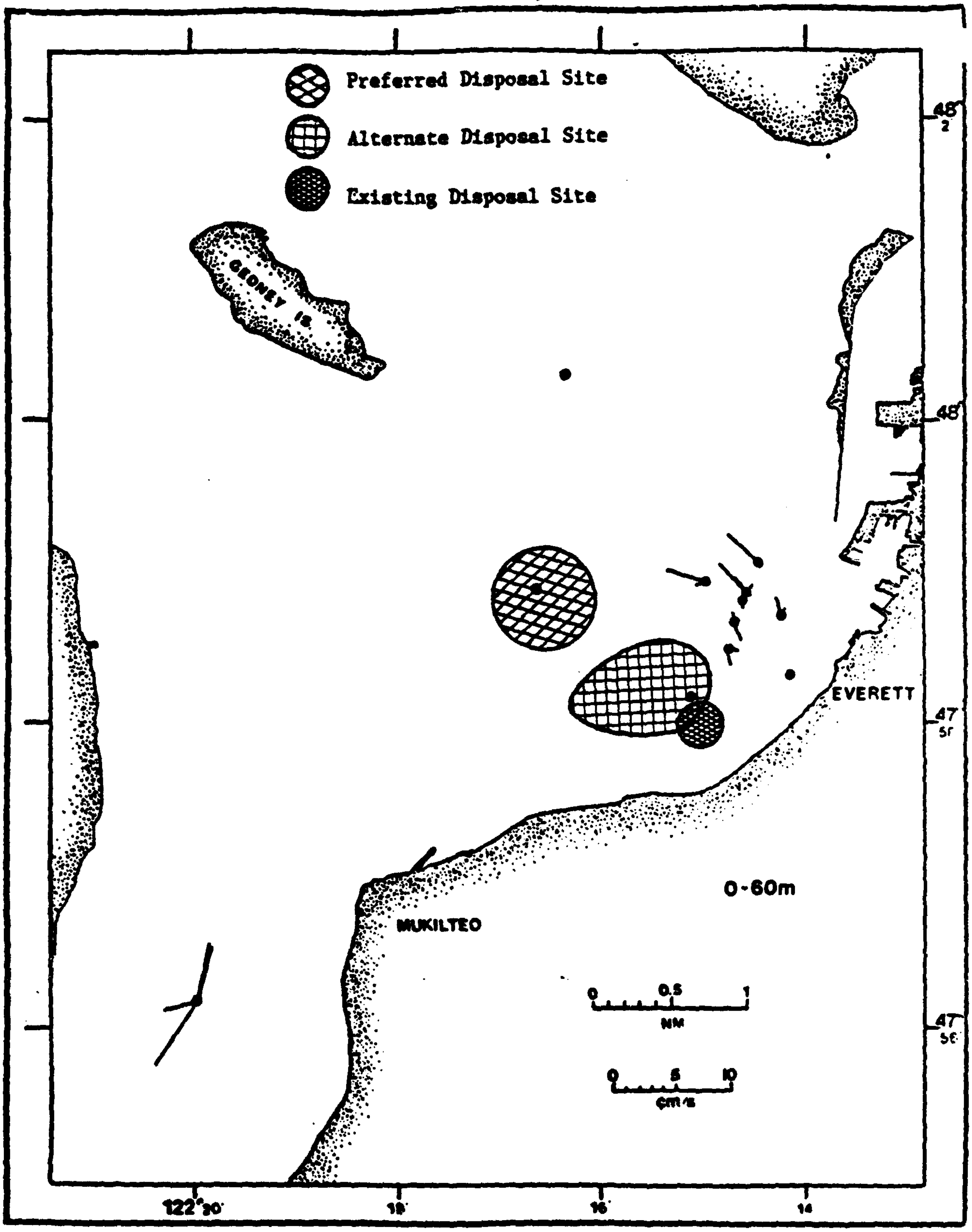


Figure II.6-23a Net current speed and direction in Port Gardner in the 0-60 meter depth range. Vectors point in the direction of prevailing currents. (Source: EHI)

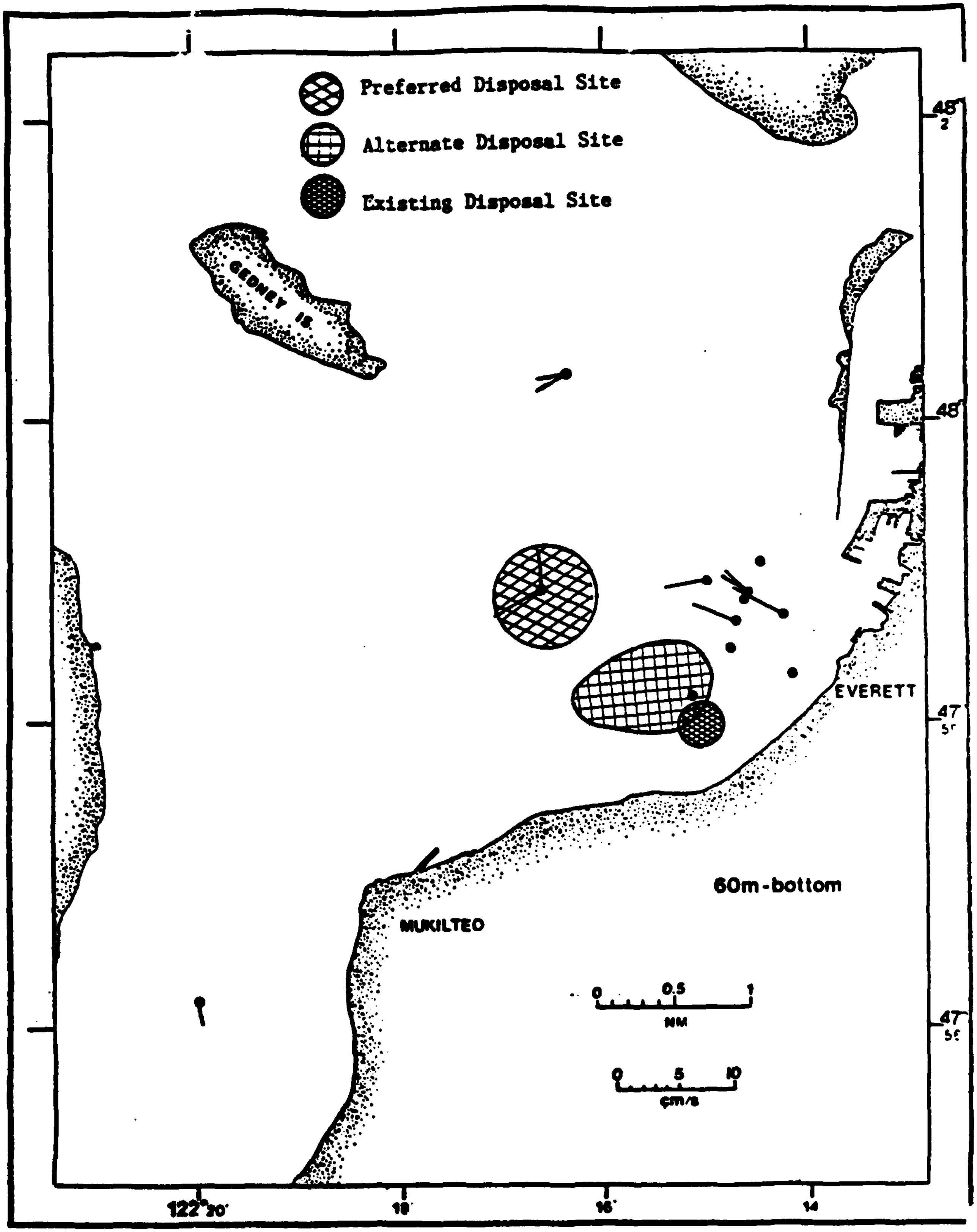


Figure II.6-23b Net current speed and direction in Port Gardner in the 60 meter to bottom depth range. Vectors point in the same direction of prevailing currents. (Source: EHI)

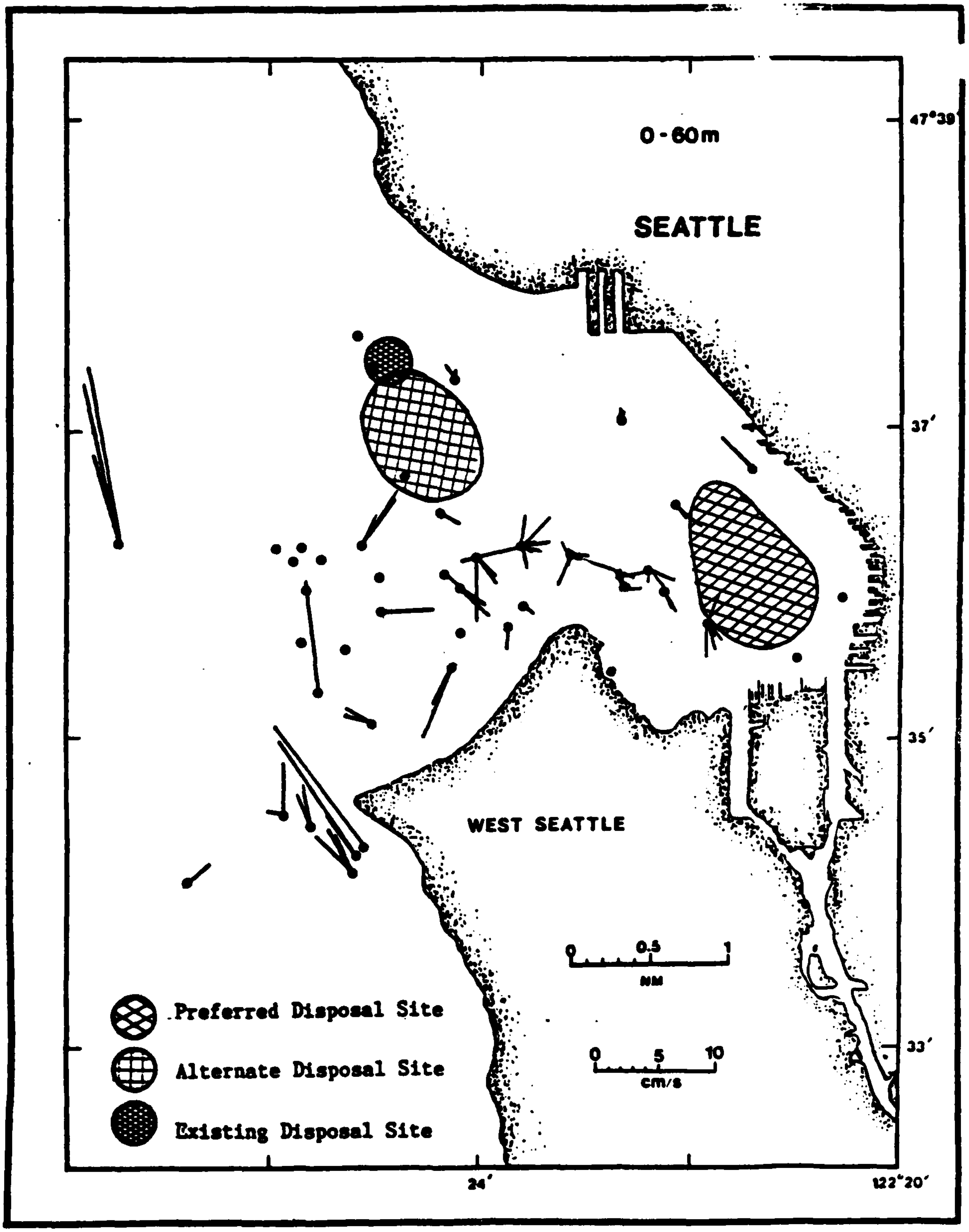


Figure II.6-24a Net current speed and direction in Elliott Bay in the 0-60 meter depth range. Vectors point in the direction of prevailing currents. (Source: EHI)

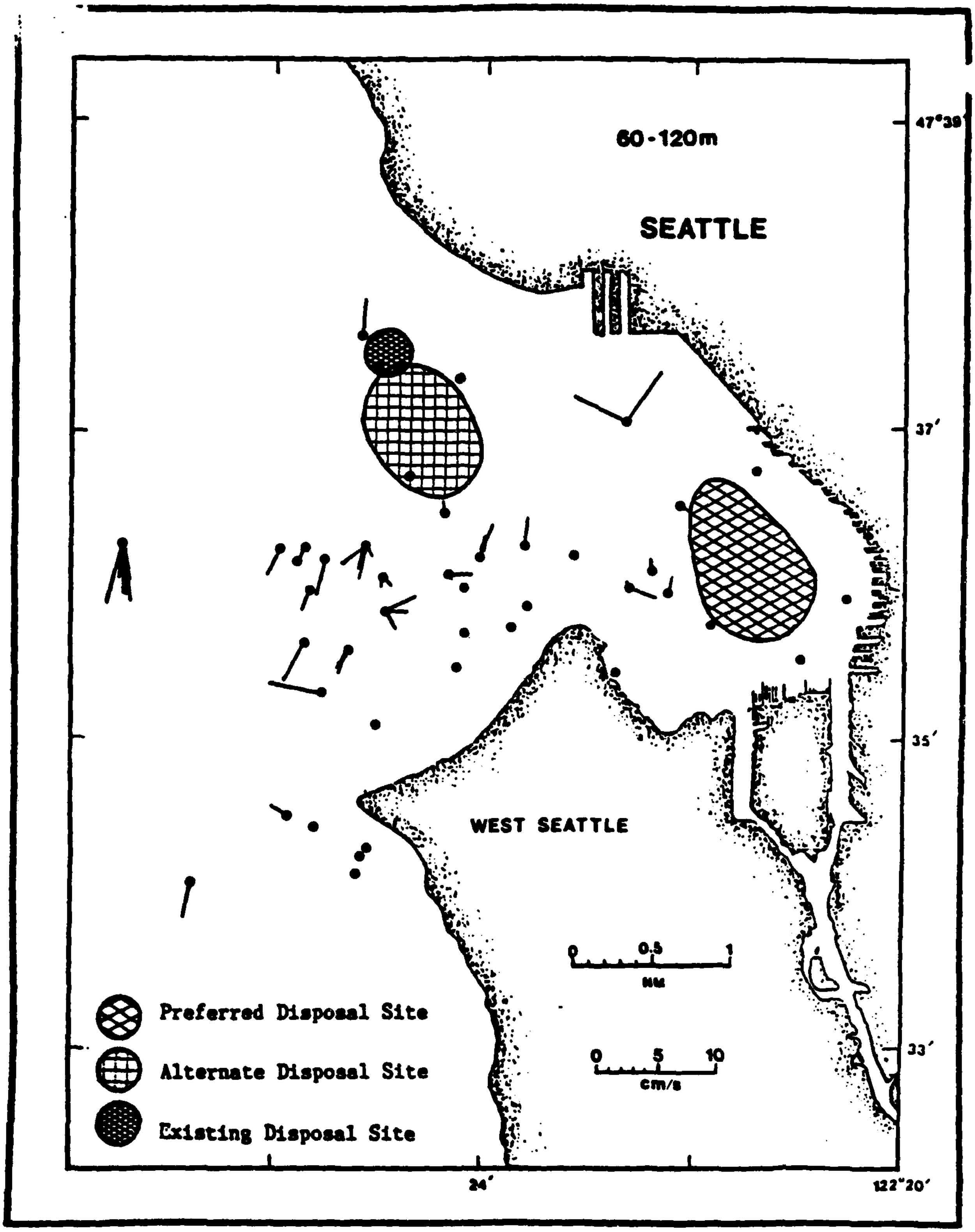


Figure II.6-24b Net current speed and direction in Elliott Bay in the 60-120 meter depth range. Vectors point in the direction of prevailing currents. (Source: EHI)

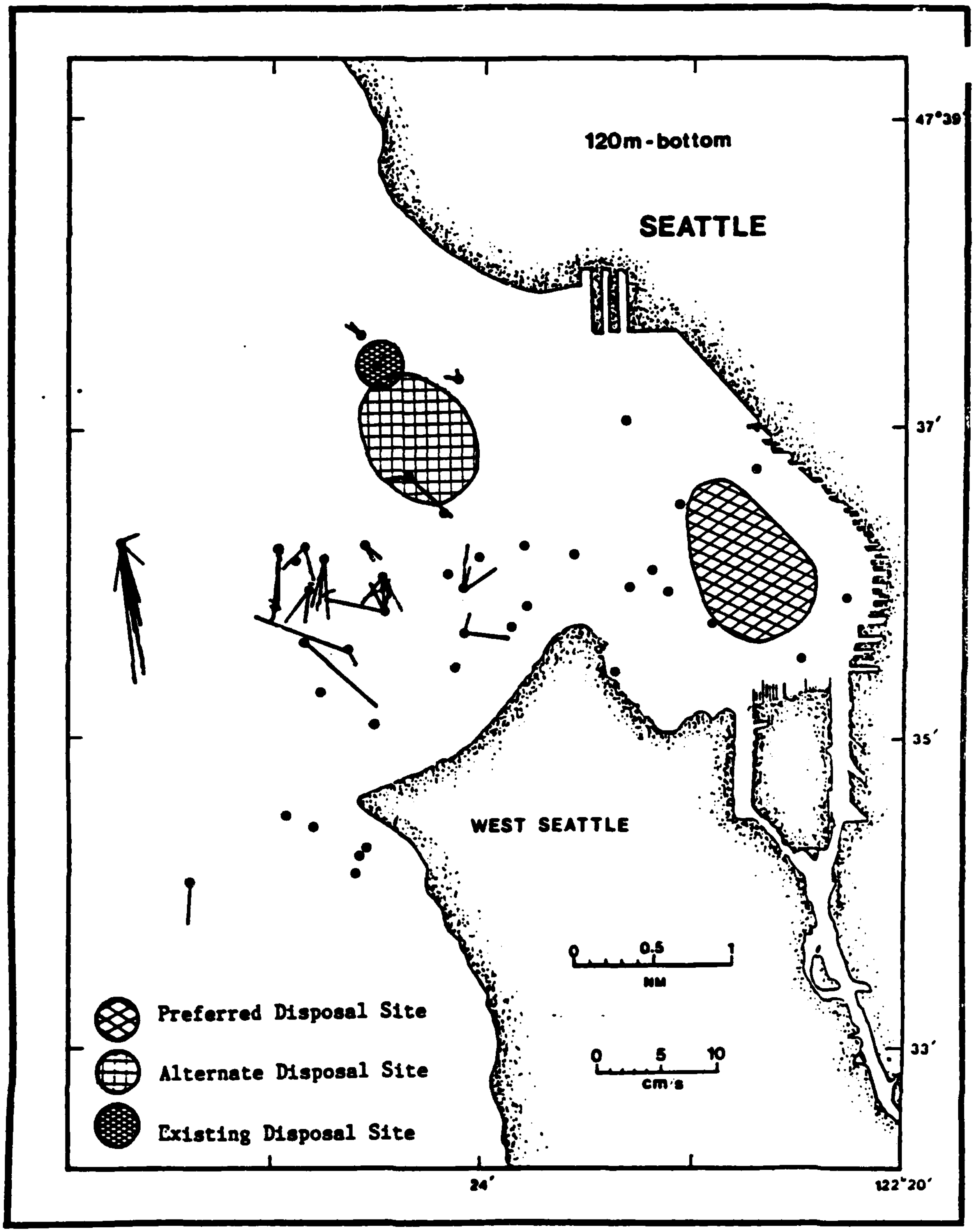


Figure II.6-24c Net current speed and direction in Elliott Bay in the 120 meter to bottom depth range. Vectors point in the direction of prevailing currents (Source: EHI)

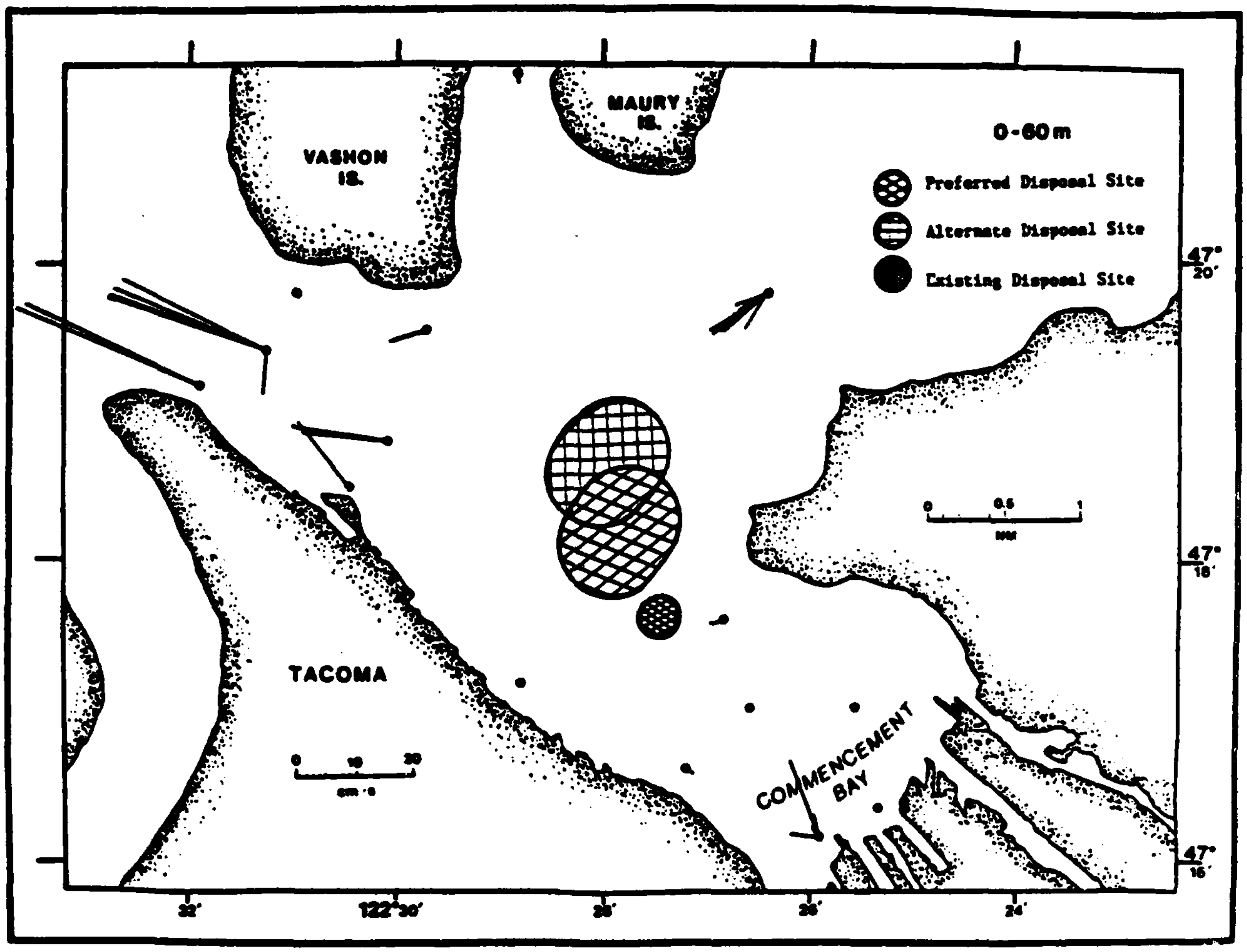


Figure II.6-25a Net current speed and direction in Commencement Bay in the 0-60 meter depth range. Vectors point in the direction of prevailing currents. (Source: EHI)

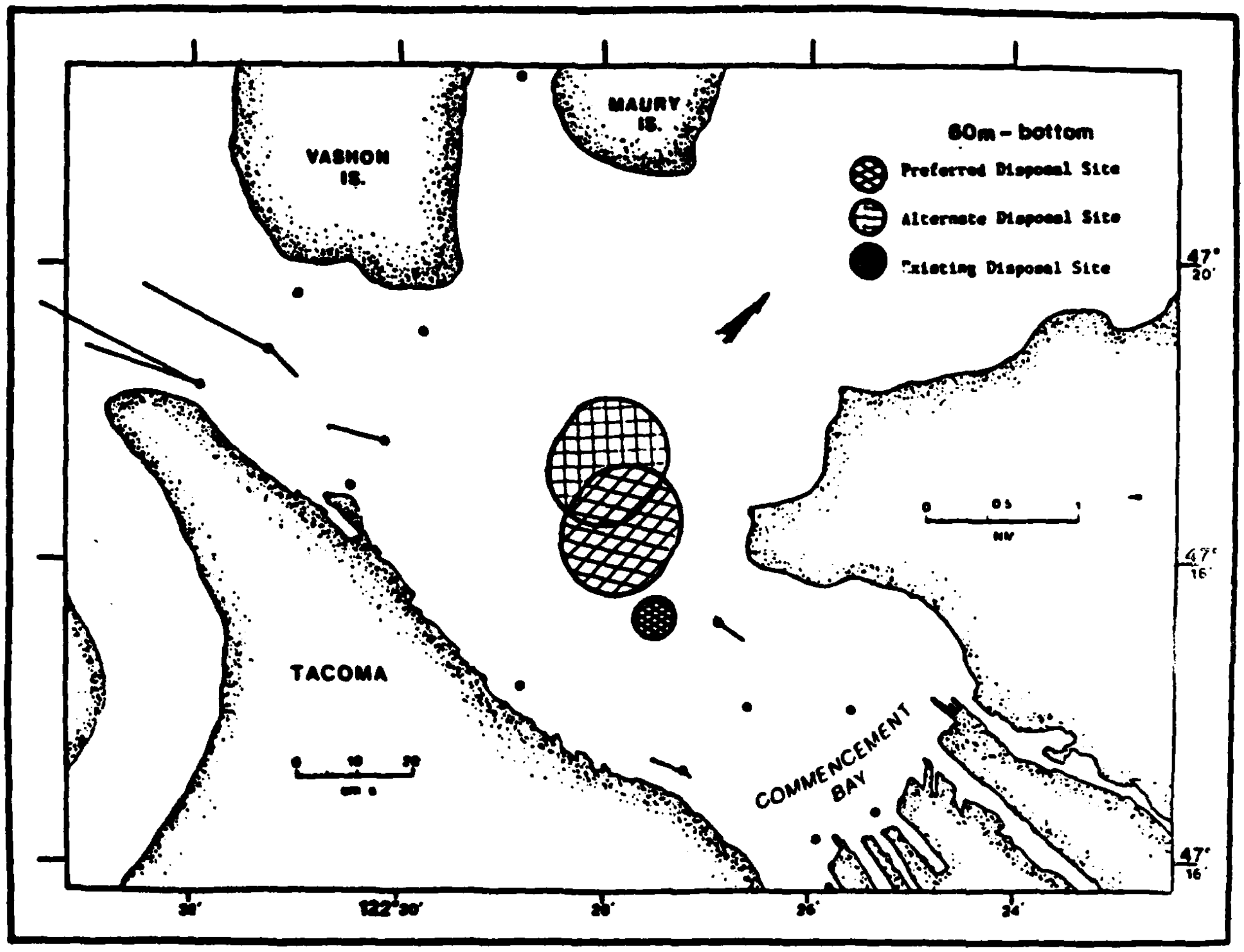


Figure II.6-25b Net current speed and direction in Commencement Bay in the 60 meter to bottom depth range. Vectors point in the direction of prevailing currents. (Source: EHI)

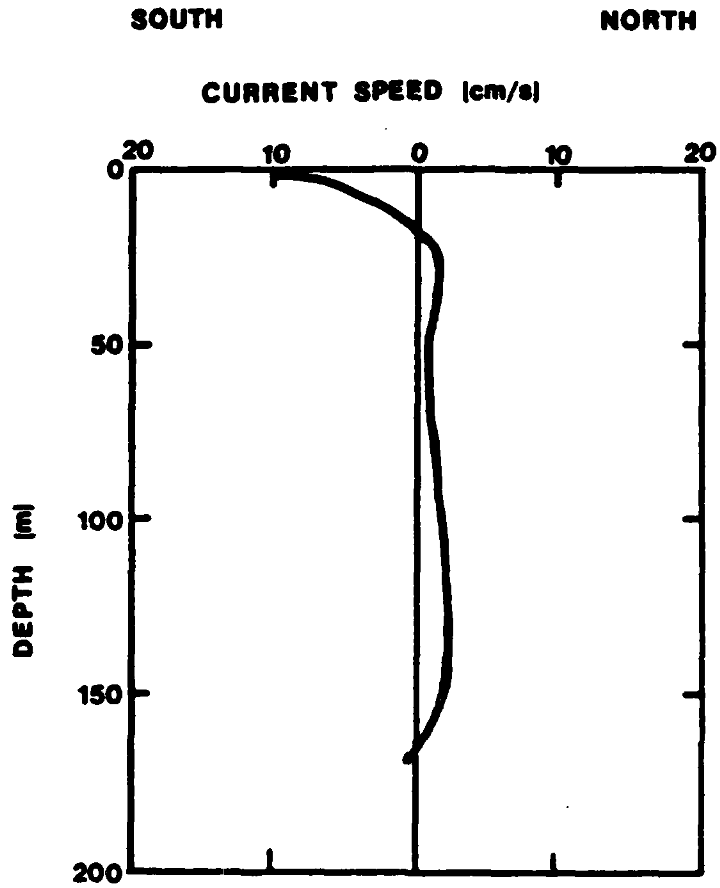


Figure II.6-26 The vertical profile of net current speed (cm/s) in the vicinity of the Saratoga Passage ZSF. (Source: Ebbesmeyer et al., 1984)

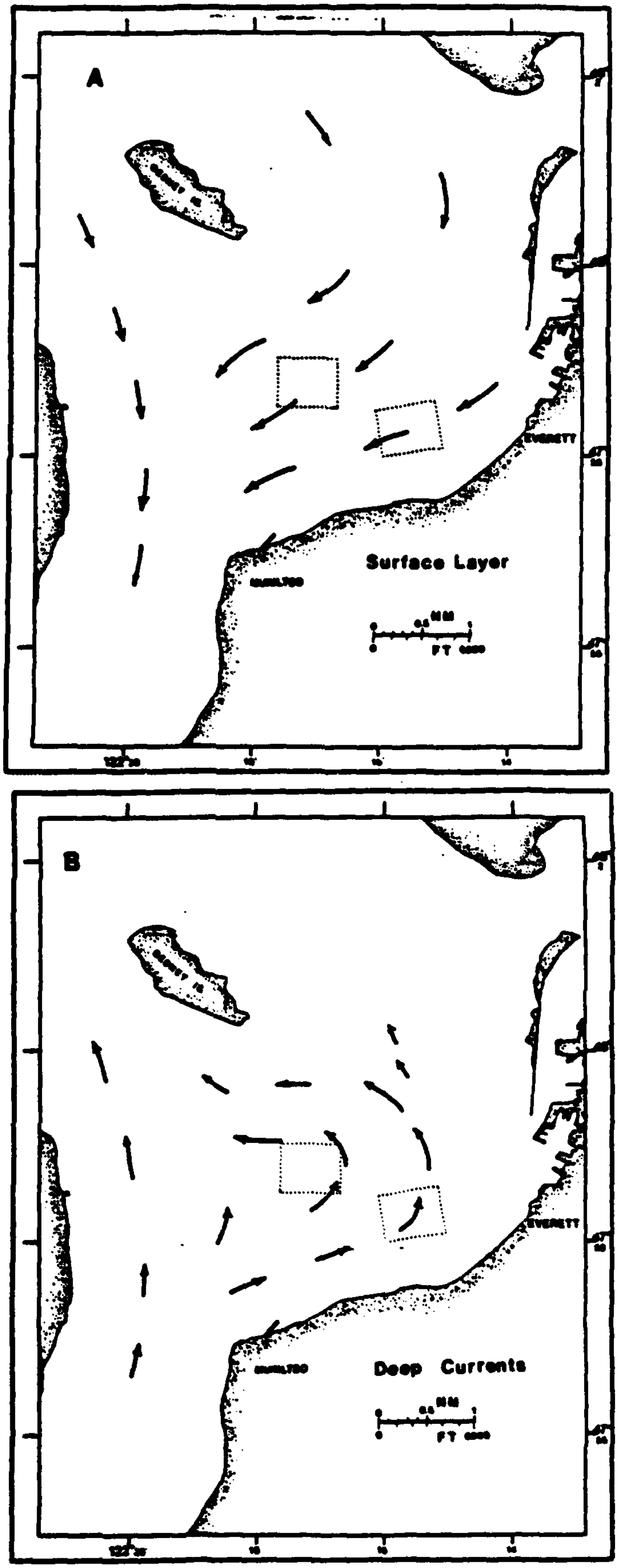


Figure II.6-27 Estimated patterns of prevailing currents in Port Gardner for the A) shallow surface layer and the B) deep layer. (Source: EHI)

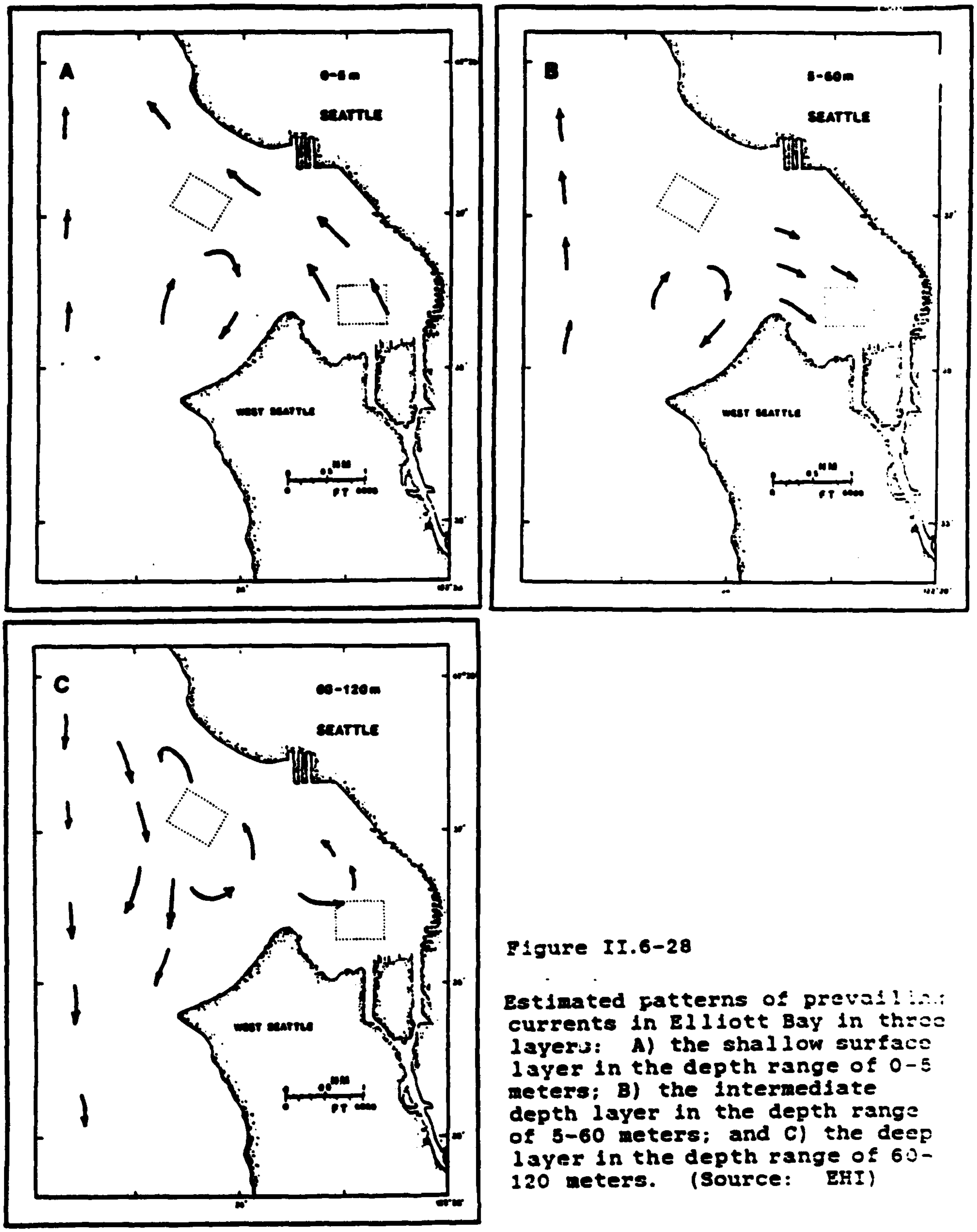


Figure II.6-28

Estimated patterns of prevailing currents in Elliott Bay in three layers: A) the shallow surface layer in the depth range of 0-5 meters; B) the intermediate depth layer in the depth range of 5-60 meters; and C) the deep layer in the depth range of 60-120 meters. (Source: EHI)

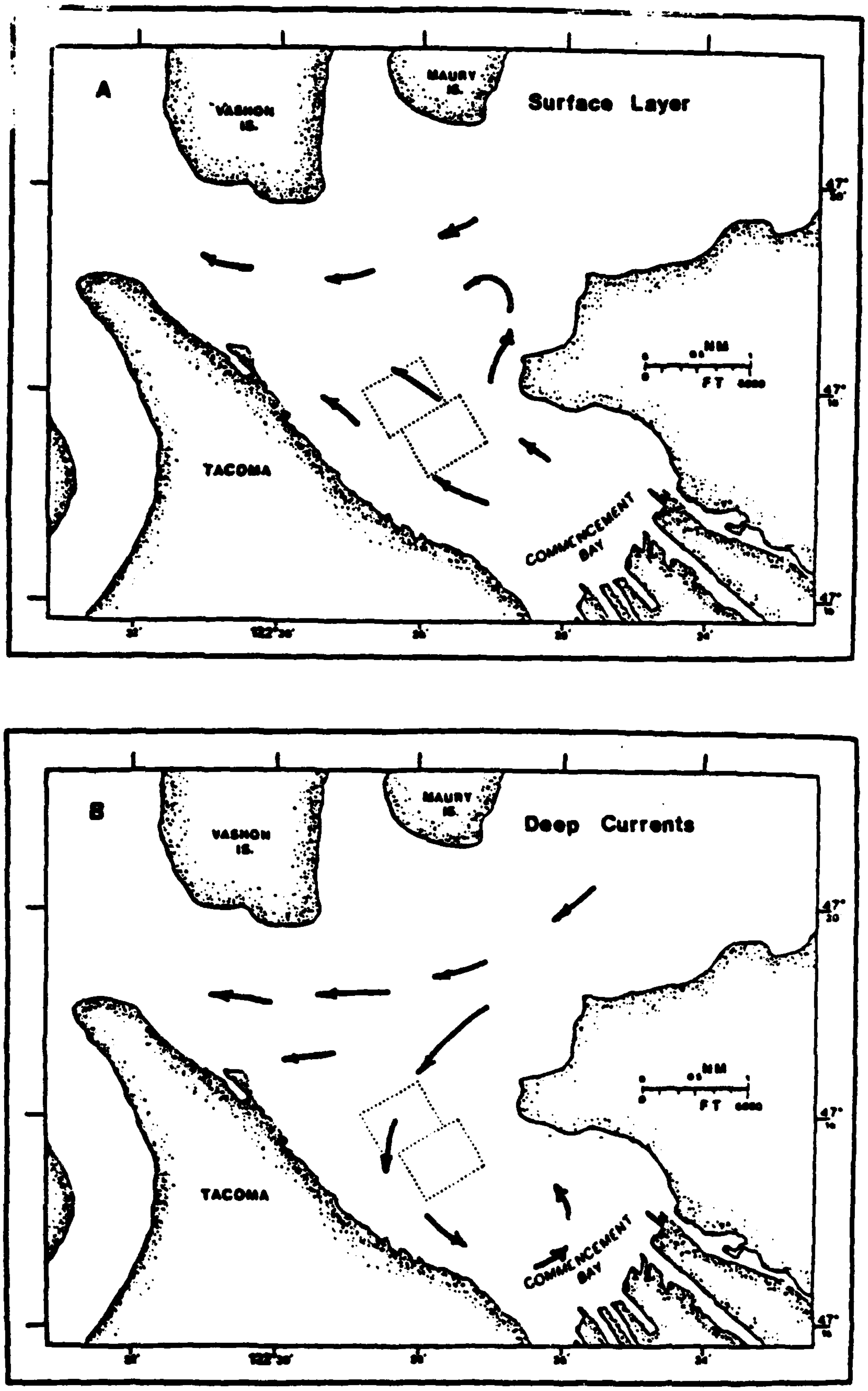


Figure II.6-29 Estimated patterns of prevailing currents in Commencement Bay for the A) shallow surface layer and the B) deep layer.

7. FATE OF DREDGED MATERIAL

Although attempts were made to locate the disposal sites where the probability of deposition was highest, undoubtedly a small fraction of the disposal material will be transported beyond the disposal site boundaries. Transport off site can occur through two mechanisms. First, a small amount of the disposal material will remain in suspension after the main mass of material reaches the bottom, and the prevailing currents may transport the suspended material, with some of it settling beyond the disposal site boundaries. Second, the material that does reach the bottom within the disposal site may become resuspended at a later time because of unusually strong currents. For these reasons, the transport, or fate, of previously deposited materials was considered.

To determine the fate of the dredged material, the behavior of previous dredged material disposal, particularly those made in Puget Sound was reviewed. Fortuitously, some of these studies were made in the two ZSFs in Elliott Bay. These studies, and one made near Dana Passage, as well as others cited in the literature, suggest a threshold speed of approximately 0.5 knot (25 centimeters/second; 0.8 feet per second) above which newly deposited dredge materials become resuspended and may move out of the disposal site. This threshold corresponds to certain contours on the maps previously given for the hydraulic characteristics (mean speed = 10 centimeters/second; variance = 100 cm2/s2; and a peak speed of 25 centimeters/ second).

7.1 Dredged Material Remaining Suspended in the Water Column

A review of the literature and discussions with personnel at the Corps Waterways Experiment Station indicate that while extensive studies have not been made of the amount of dredged material that remains suspended in the water column after a disposal operation (B. Johnson, personal communication), enough observations have been made immediately after a disposal event to give a relatively good indication. One was at Fourmile Rock, another was in Elliott Bay, and a third off the Washington Coast at Grays Harbor indicate that the amount of material remaining suspended in the water column is approximately one percent of the amount barged to the disposal site.

The following description was adapted from Schell et al. (1976) who described the amount of material remaining in the water column after a disposal was made at the Fourmile Rock ZSF. For these samples no grain size analysis was done. However, recent measurements made by the Seattle Corps indicate that the dredged area is typically composed of black silt containing some sand.

During March 1974, vertical profiles of light transmittance were made before and immediately after a disposal operation at the existing Four Mile Rock disposal site. Figure II.7-1 presents the mean and standard deviation of fifteen transmittance profiles made close to the location of the disposal. These profiles show depressions of light transmittance that were apparently associated with clouds of dredged material that were evident immediately after the barge released the dredged material. Total particulate matter (TPM) was measured within several clouds. The TPM values in four clouds varied between 2-5 milligrams per liter compared with typical background values of 0.5 - 1.0 milligrams per liter.

The observations of particulates remaining in the clouds may be used to estimate the dredged material remaining in suspension immediately after a disposal operation. The weight (W) of material can be expressed mathematically as follows:

$$W = L \times Wi \times H \times C \times N,$$

where L, Wi, and H are the length, width, and height of a cloud, respectively; C is the concentration of particulate matter in the cloud; and N is the number of clouds resulting from the disposal operation.

Based on the observations at Fourmile Rock, C and N are approximately 5 milligrams per liter and four clouds, respectively. The value of H was typically ten meters as indicated by Figure II.7-1. Observations of the horizontal extent of water parcels off West Point by Bendiner (1975) suggest that L and Wi are on the order of 100 meters. Substituting these values into the equation for W yields approximately two tons. This is equivalent to only 0.2% of a typical 1000 ton disposal, or a slight amount.

Schell et al. (1976) also considered a hypothetical vertical plume of suspended particulates extending from the barge to the sea floor immediately after disposal. They estimated that, at a maximum, 11.5 tons would remain suspended, or almost 1% of a 1000 ton disposal operation.

The foregoing considerations suggest that, on the order of one percent of the dredged material may remain suspended for a time after a disposal operation, depending on the composition of the material.

A study by WES made on 24-26 February, 1976 at the inner Elliott Bay disposal site showed that the effects of the disposal operation were detected within 25 meters of the bottom (Bokuniewiez et al, 1978). This occurred after discharge of 1200 cubic yards of black, fine-grained, sandy organic silt in a depth of approximately 60 meters. A small amount of material remained in suspension within 25 meters of the bottom for about an hour after the disposal (Fig. II.7-2).

The assumption that none of the dumped material is lost to the water body during convective descent is supported by dredged material disposal monitoring in the lower part of Grays Harbor in 1982, in which no increse in suspended sediment concentrations were observed within the water column at a station located 1,000 meters from the dump site (Trawle and Johnson, 1986). The fact that nothing was detectable indicates that loss to the water column during descent was minimal.

An important factor in determining sediment fate is the composition of the sediment being disposed. During the dredging operation the clamshell dredge can deliver sediments in a near "in situ" condition. The "clumpiness" of the clamshell sediments allows the disposal operations to be more predictable, with sediment fate more easily controlled (Corps, 1986). Tests have shown that this material, disposed of by dumping, tends to remain more or less intact and falls to the bottom as a mass at a high rate of speed (Fig. II.7-3). These clumps attain their terminal velocity quickly after release from a barge and do not accelerate further with depth. After impact, the material breaks up and its ultimate dispersion is dependent on ambient currents and bed slope at the point of impact.

In another, more recent, experiment by WES numerical modeling was used to predict the behavior of dredged material (Adamec et al., 1986). The model assumed that disposal took place in 265 - 400 feet of water. Each barge load contained 4,000 cubic yards of sediment which was composed of 25% wood chips, 22% sand, and 53% silt-clay (bulk density 1.25). Sediment properties were assigned based on East Waterway, Everett Harbor, sediment characteristics. Model coefficients for bottom friction and diffusion were based on calibration using previous Elliott Bay data with modifications to reflect changes in depth and water currents.

Seven surface barge dump model runs were made with varying currents and sediment compositions. The predictions of percent of the sediment fractions and the total percent remaining in near bottom suspension 3600 seconds (60 minutes) after disposal are presented in Table II.7-1. For all sets of current and material compositions, the total percentage of sediment remaining in suspension longer than 60 minutes was about two percent of the total (varying between 2.3% and 1.2%; Ademec et al., 1986). In areas of low current, a large portion of this suspended material will eventually settle in the disposal site. Note that these estimates do not include any material that may have been stripped from the descending mass of material (previously estimated at approximately 1%).

Based on current data collected at the proposed Navy site (Nortec, 1986), the medial current speeds vary from approximately 0.26 feet/second at the surface to 0.11 feet/second near the bottom. The sediment remaining in suspension longer than 3000 seconds was 1.3%. A single model run was also conducted

for a surface dump of contaminated material in a depth of 400 feet. The results indicate 2.3% of the material remains in suspension after a time period of 3600 seconds. It should be noted that this figure is probably at the accuracy limit of the currently available models.

The model results also indicate that it is the sand fraction that had the longest settling time. In the actual disposal process, as the clay/silt particulates flocculate and fall through the water column, with a settling velocity greater than that attached to the sand fraction, they will probably entrap and carry a significant portion of the fine sand to the bottom more rapidly than depicted by the model. The ability of the model to accurately portray the material fate decreases as the percent of material in suspension decreases and as the time of the simulation increases. At the point where the percent suspended becomes less than two percent and the time exceeds 3600 seconds, other uncertainties such as how much material dissociates from the cloud in the descent phase and the influence of turbulent diffusion become extremely important factors.

Although the models do need additional field verification, a wide range of data verified that the models do compute the proper behavior of dredged material disposed at open-water sites (Bokuniewiez et al., 1978). In these field studies, water depths ranged from 60 to 220 feet and dredged material included dense, cohesive silt-clay dug with clamshell buckets as well as sand and dilute silty material from hopper dredges. The quantities released ranged from 30 to 6,000 cubic yards. In all cases, it was observed that less than one percent of the descending mass was stripped from the descending cloud. Within a few minutes about 95 percent of the material had settled to the bottom within a radius of a few hundred feet. The maximum thickness of the bottom surge was about 15 percent of the water depth in all cases. Thus, for a depth of 400 feet, for the typical PSDDA site, the maximum thickness of the collapsing cloud on the bottom would be about 60 feet, or 18 meters. Assuming the worst case of particle settling of 0.0017 feet per second yields a time of about 35,300 seconds (about ten hours) required for the remaining five percent to be deposited. In a site that has a radius of approximately 2000 feet, with the disposal zone at the center, and a bottom current of 0.1 feet per second (3 centimeters per second), a time of 20,000 seconds would be required to transport a sediment particle out of the site. Thus, an additional two to three percent of the dredge material will be deposited within the site, leaving two to three percent that will be transported beyond the site.

7.2 Resuspension Probability

Current velocity affects the distribution of sediment particle sizes in unconsolidated soft bottom material. Coarser sediments are associated with higher current environments, while fine-grained sediments are associated with lower energy environments. For example, a current velocity of 0.4 knot (20.6 centimeters per second) will shift ordinary sand along the bottom, while a current of one knot (51.5 centimeters per second) will shift fine gravel. A current of 2.15 knots (111 centimeters per second) will move coarse gravel 2.5 centimeters in diameter, and 3.5 knots (180 centimeters per second) will move angular stones up to 3.8 centimeters in diameter (Moore, 1958). Therefore, to a substantial degree currents determine the grain-size distribution of sediments. Figure II.7-4 illustrates the relation between current velocity and its potential to deposit, transport, and/or erode sediments of various grain sizes.

Studies of mounds of dredged material have been conducted to determine if the material was transported from the initial disposal site. Examinations were made of disposals at the ZSF in inner Elliott Bay, the disposal area in outer Elliott Bay off Fourmile Rock, and near Dana Passage in southern Puget Sound.

Fortunately these three studies span a wide range of current speed and embrace the threshold for movement of dredged material. In inner Elliott Bay the currents were too weak to resuspend sediments; at Fourmile Rock the currents occasionally resuspend some dredged material; and at Dana Passage photographs of the dredged material on the bottom clearly demonstrated that the material is resuspended above the threshold of 25 centimeters per second.

7.2.1 Low Current Regime - Inner Elliott Bay—

The River and Harbor Act of 1970 authorized the Dredged Material Research Program (DMRP), a comprehensive, nationwide study of dredged material disposal. The DMRP studies included a site in the ZSF in inner Elliott Bay (Fig. II.7-5; Sweeney, 1978; Tatem and Johnson, 1978). This site, monitored for approximately four years after disposal in 1976, was selected for long-term monitoring under the Dredging Operations Technical Support (DOTS) Program. The studies were intended to determine if the disposal material remained at the disposal site. This summary is based on reports describing the Elliott Bay work by Dexter et al. (1984) and Tatem (1984).

An accidental spill of 984 liters of PCB occurred in the Duwamish River in September 1974 (Tatem and Johnson, 1978) and settled in bottom sediments. The PCB contaminated sediments were removed by dredging where most of the material was removed using

special dredging techniques designed to minimize release of the material to the water, during February 17 - March 6, 1976. Some of the upper Duwamish contaminated material was dredged and placed at the experimental test site which coincidentally falls within the inner Elliott Bay ZSF. The PCB was a tracer of the sediment allowing documentation of the location and movement of the dredged material.

Approximately 150,000 cubic yards of sediment was removed and subsequently deposited in the test disposal site (Fig. II.7-5) using tandem 500 - 700 cubic yard capacity barges with bottom-opening doors. The depth at the disposal site was approximately 200 feet.

The DMRP studies examined various environmental samples taken before, during, and nine months after the disposal operation of February-March 1976. Sampling stations for the DOTS study were chosen at and near the previous disposal site stations. Other stations both within the DMRP sampling grid as well as in the surrounding area were chosen in a random fashion. Four separate cruises were conducted in the vicinity of the disposal area: a reconnaissance cruise in February 1979; and cruises in May 1979, October 1979, and May 1980.

Bathymetric surveys made by the Corps Seattle District were used to construct bottom contour maps of the Elliott Bay disposal area. The disposal created a mound of dredged material 2.0 - 2.5 meters (5.5 - 7.0 feet) in height near the center of the disposal area. The bathymetric data indicated little or no change in the disposal area between 1976 and 1979.

Currents at the disposal site were measured using current meters deployed at selected distances above the bottom. Extreme value statistics, which are maximum one year current speeds as described in Hinchey et al. (1980), were estimated to determine whether the currents were sufficiently strong to transport the sediment. It was observed that the sediment was generally cohesive and difficult to move. The data indicated that the currents were weak, moved primarily in response to tidal fluctuations, and apparently did not move much of the sediment; therefore, the area could be characterized as depositional rather than erosional. It is possible that some silt and clay could have been suspended or resuspended for a small percentage of the time; however, bottom photographs were very clear, indicating little resuspension of sediment particles.

Earlier work at this disposal site indicated that the total PCB levels and the type (degree of chlorination) of PCB could be used to discriminate between dredged material and the natural sediments of Elliott Bay; however, sediment analyses for PCB showed a high degree of spatial heterogeneity. In some cases samples from the same area, separated by relatively minor vertical or horizontal distances, showed large differences in PCB concentration. This made it difficult to establish trends and to delineate the disposed material. An earlier conclusion of the

DOTS study was that much of the dredged material from the Duwamish River had been distributed deeper in the sediment layers due to biological activity, while natural sedimentation covered some of the material. Using the highest total PCB values obtained from all of the sampling stations, Dexter et al. (1984) constructed contour plots of PCB concentrations in the area of the disposal site (Fig. II.7-6; data contours of the February 1979 reconnaissance cruise only). Elevated PCB levels were clearly associated with the sediments at the disposal site. The range within the disposal grid was 0.46 parts per million to 7.73 parts per million total PCB (total PCB abbreviated hereafter as t-CB) on a dry weight basis. Trichlorobiphenyls (abbreviated hereafter as 3-CB) were at higher levels in the dredged material than background sediments. The 3-CB levels of 0.3 to 0.4 parts per million in the mound were approximately three to four times higher than other areas of Elliott Bay.

The PCB data from the reconnaissance cruise of February 1979 was subjected to cluster analysis and showed that the majority of the disposal site samples fell into one group; samples high in both t-CB and 3-CB with some discrepancies. Some stations from the corner areas of the disposal site did not fall into this group whereas some outside stations did. Two central stations showed some surface material that did not fall into this group as would be expected. The following tabulation compares data from the DMRP study on PCB levels in the upper 10 centimeters of sediment at the center of the disposal grid with data from the DOTS study. The comparison indicates that no major changes in overall PCB levels occurred through 1980. In general, the PCB analyses supported the results of the sediment texture analyses and indicated that the dredged material mound had not changed since the DMRP studies.

Study	Sample Date	t-PCB (ppm)
DMRP	Mar 76	2.20 ± 1.2
	Apr 76	2.13 ± 0.9
	Jun 76	2.19 ± 1.1
	Sep 76	2.94 ± 1.3
	Dec 76	3.44 ± 2.1
		2.58 ± 0.59
DOTS	May 79	2.70
	Oct 79	2.21 ± 0.89
	May 80	3.54 ± 2.4
		2.82 ± 0.68

Analysis of the complete data set for the water-column samples indicated no significant differences between PCB levels in either water or suspended particulates for the various stations. These PCB values were not related to any previous disposal of contaminated dredged material.

The results of the DMRP and DOTS studies indicated that the dredged material deposited at the ZSF in inner Elliott Bay was stable both physically and chemically over a four-year period. The disposed material apparently has not been moved by currents.

7.2.2 Intermediate Current Regime - Fourmile Rock--

During September 1974, a core was retrieved from the Fourmile Rock disposal site (Schell et al., 1976). A visual examination of this core showed depletion of fine particles (silt and clay) in the upper layers. The core was sectioned and dated by Lead-210 (210Pb) dating techniques, and then analyzed for trace metals. Trace metal concentrations versus depth in the core and the 210Pb values used to determine the sedimentation rate are shown in Figure II.7-7.

For determination of sedimentation rate, the cores were divided into one centimeter sections, and the 210Pb activity in each section determined by alphaspectroscopy. The 210Pb activity presented in Figure II.7-7 shows three separate parts: 1) from the surface to a depth of 7 centimeters where the 210Pb activity increases with depth; 2) from 7 to 21 centimeters the 210Pb activity remained constant; and 3) from 21 to 42 centimeters the 210Pb activity decreased with depth. The third section represents what was believed to be the natural 210Pb concentrations in the sediments because the values decrease in a predictable manner. The second section suggested recent deposits of dredged material because the 210Pb content is nearly constant with depth. Schell et al. (1976) suggested that the finer material, containing most of the 210Pb, was carried away by bottom currents as indicated in the first section of the curve. They cited the trace metal profiles presented in Figure II.7-7 as further evidence of the erosion.

7.2.3 High Current Regime - Dana Passage--

Between July and December 1972, a dredging experiment was conducted in which approximately 20,000 cubic yards of material was dredged from Olympia Harbor, transported by hopper barge, and released in the vicinity of Dana Passage (Sternberg and Collias, 1973; Fig. II.7-8). The disposal site was situated in a water depth of approximately 108 feet on a small plateau in an area characterized by relatively strong tidal currents and a bed of medium sized sand.

Dana Passage is a relatively large tidal channel located in southern Puget Sound (Fig. II.7-8). The channel is approximately two miles long, 0.5 miles wide, and 120 feet deep. The tidal flow ebbs predominantly from the southwest through Dana Passage and then turns southward toward Nisqually Reach. Historical current data collected by Cox et al. (1984) show that the total variance of the current lies in the range of 200 - 1000 $cm^2\ s^{-2}$; therefore, these currents are much stronger than at Fourmile Rock and inner Elliott Bay.

The disposal area is located near the northeast entrance to Dana Passage. The bathymetry in this region is relatively complex consisting of shallow and intervening depth areas. The dredged material consisted of silt- and clay-sized particles and, due to its textural dissimilarity with the local bottom sediment, could be easily identified via standard grain size analysis at the disposal site. This experiment presented a unique opportunity to observe the fate of newly deposited dredged material in an area having strong tidal currents.

On 10 August 1972 samples were collected at 39 stations using a van Veen Grab Sampler. All samples were subjected to a standard size analysis to determine the textural characteristics of the bottom sediment prior to disposal. The mean size varied from granules and pebbles within Dana Passage, to medium and coarse sand at the disposal site. Silt and clay-sized materials occurred north and south of the disposal site. The distribution of mean grain size appears to be well correlated with the tidal currents in the area. Sediments are very coarse within the channel where currents are strong; medium to very fine sand in the vicinity of the disposal site; and fine in the adjacent inlets where currents are weak.

During the disposal operation individual samples of the dredged material were collected from the hopper barge. Size analyses gave a composite textural profile of the dredged material with a mean grain size of fine silt. The four bottom samples surrounding the disposal site each contained greater than 58% sand and less than 15% clay, whereas the dredged material contained less than 35% sand and greater than 15% clay.

Current meter stations were maintained in the vicinity of the disposal site in October, 1972. A tripod mounted current meter system was set on the bottom about 1,200 feet west of the marker buoy established as the disposal site. The bottom tripod was designed to measure current speed, direction, and pressure fluctuations one meter above the sea floor each half hour and to take a photograph of the bottom.

During the experiments five loads of dredge material were dumped. Analyses of the photographs of the bottom indicated that turbidity varied from very low to very high. In some instances, cloudy photographs resulted from the actual dumping operation, while in other instances bottom currents were sufficient to cause erosion and thus create high turbidity.

The relationship between bottom current speed, occurrence of disposal operation, and relative turbidity are illustrated in Figure II.7-9. The arrows over the top of each curve labelled "D" refer to times of disposal operations. The arrows under each curve refer to the degrees of turbidity (S, small; M, medium; H, high; and VH, very high). In all other bottom photographs significant turbidity was not observed. High turbidity levels associated with disposal operations can be seen at 1200 and 1700 on October 6 and at 1500-1800 on October 12. Since the tripod was located downstream from the disposal site on the flood tide, no turbidity was observed in association with the disposal at 1709 on October 5 because it coincided with the beginning of an ebb cycle.

High turbidity levels resulting from bottom erosion were observed the following times: 0130 and 1300-1400, October 5; 0200 and 1400, October 6; 0000 and 0500-0530, October 12; 0000 and 1800-1830, October 13. The results suggested that these turbidity maxima resulted from the erosion of the dredged material. The size characteristics of the material would dictate that it be transported in suspension if eroded; whereas the sandy material normally found in this area should move as bedload considering its size characteristics and the observed currents (Sundborg, 1967; Sternberg, 1972).

All occurrences of turbidity caused by erosion were associated with bottom currents ranging from 0.46 to 0.56 knots (0.8 to 0.9 feet per second). This apparently represents a threshold speed for erosion of the newly deposited dredged material. As dewatering and consolidation of the dredged material deposit occurred, higher bottom currents will be required to cause erosion (Southard et al., 1971).

7.3 Determination of the Threshold Speed

Considered together, these three examples were used to determine the threshold speed at which future dredged material will be transported in the ZSFs. The sediments of prime concern are the materials containing large amounts of silt.

The characteristics of sediments previously dredged in Everett Harbor and Hylebos Waterway (Table II.4-1), indicated substantial amounts of medium silt to clay type material will be released in the Port Gardner and Commencement Bay disposal sites. Fortunately, the observations near Dana Passage and off Fourmile Rock both apply to dredged material having substantial amounts of silt (i.e., earlier it was noted that the Dana Passage dredged material had a mean grain size of fine silt, and the Fourmile Rock dredge material had been depleted of silts and clays).

The most direct observation of the threshold for resuspension comes from Dana Passage where a speed of 25 centimeters per second was sufficient to resuspend the fine material. Fourmile Rock has 1% extreme speeds within 5-6 meters of the bottom equal to 22-27 centimeters per second (Fig. II.6-16). If the threshold seen at Dana Passage is equated to a 1% speed, then the regression in Chapter II.6 yields an rms speed of 10 centimeters per second or a total variance of 100 cm2 s-2. In other words the threshold would be exceeded only 1% of the time, at an average rate of a few hours at a time, or 3.7 days a year; therefore, it was estimated that recently deposited dredge material would undergo little transport in areas where the 1% speed and total variance are less than 25 centimeters per second and 100 cm2 s-2, respectively.

The threshold speed chosen for PSDDA is approximately equal to the speed at which silt begins to be transported by currents as shown from earlier work in Figure II.7-4. However, recent studies in Puget Sound have shown that after a time the threshold speed may increase because of "biological armoring." In these studies Striplin et al. (1985) lowered a flume into the bottom at 600 feet depth in Elliott Bay and slowly increased the speed within the flume until the silt material on the bottom began to erode. Video photographs were made of the bottom as it began to erode. Repeated experiments showed that erosion was slight until speeds of 40-50 centimeters per second were reached. In that speed range substantial amounts of bottom sediments began to be transported by the currents in the flume. The photographs indicated that the bottom was bound together by some biological activity. Apparently the working of the sediments by benthic organisms caused the bottom to be bound together. Although these experiments were of a preliminary nature, the threshold speed in Puget Sound apparently increases from 25 centimeters per second for newly deposited materials to approximately 50 centimeters per second after the material has been in place for some time.

7.4 Dilution of Suspended Material

The results presented in section II.7-1 indicate that approximately one percent of the dredged material may remain suspended in the water column beyond the boundaries of the disposal zones. This is the material that is stripped from the dredged material as it descends to the bottom. To evaluate the possible impacts of this material it was assumed in the worst case that it remains suspended for enough time to be transported by the prevailing currents throughout the three embayments (Port Gardner; Elliott Bay; and Commencement Bay). Because the currents are weak and variable in these embayments and because of the few data available, it was not possible to evaluate preferred locations to which the suspended material might be transported. Therefore it was assumed that the suspended material will eventually settle within the embayments. This is

considered a worst case because some of the material would probably be carried out of the embayments into greater Puget Sound.

The potential impact of the suspended material was evaluated by considering its dilution defined as the ratio of the natural sedimentation divided by the suspended dredged material. The dilution was expressed mathematically as

$$D = \frac{A \times r}{(M15/15) \times (0.01)} ,$$

where A is the area of the embayment (square kilometers), r is the natural sedimentation (centimeters per year), M15 is the amount of dredged material to be disposed of during 1985-2000 (cubic yards, converted to cubic meters), and the factor 0.01 represents the 1% of the dredged material that remains suspended in the water column.

TABLE II.7-2 ESTIMATED DILUTION OF SUSPENDED DREDGED MATERIAL FOR ML1 AND ML2 CATEGORIES OF MATERIAL.

Embayment	Area (km2) A	Deposition Rate (cm/year) r*	Dredged Material (cubic yards 1985-1999)	Dilution D
Port Gardner	34	0.86	2,690,000	214
Elliott Bay	14	2.14	5,119,000	115
Commencement Bay	29	1.81	3,270,000	319

*From Lavelle et al. (1986)

Table II.7-2 lists the estimated dilutions and the factors that were used to evaluate them. ML1 and ML2 categories of material are defined in the EPTA.

In the evaluation it was further assumed that categories ML1 and ML2 dredged materials will be deposited in the disposal sites. Given the previous assumptions the estimated dilutions range between 115 for Elliott Bay and 214 for Port Gardner, to 319 for Commencement Bay.

The foregoing calculations indicate that if the material stripped from the descending mass were to be evenly distributed throughout the sediments of the embayments, it would comprise between 0.3 and 0.9% of the bottom sediments. Since the suspended material will not be distributed evenly it is possible that higher concentrations may be obtained in local areas. On the other hand some of the material may be transported out of the embayments thereby increasing the estimated dilutions. Probably the most that can be said is that the concentrations of suspended material in local sediments beyond the disposal site is on the order of one percent. Since the dredged material is defined to be clean it is not expected that this amount of material will cause detectable impacts on benthic communities.

TABLE II.7-1 RESULTS OF MODEL RUNS FOR DISPOSAL OF ONE BARGE LOAD OF CONTAMINATED MATERIAL AT THE SURFACE AT MODEL TIME 3600 SECONDS (60 MINUTES).

Run	Depth (ft)	Current speed (fps)	Clump factor (%)	Percentage Remaining in Suspension: Sand	Silt-Clay (%)	Wood (%)	Composite (%)	Deposition: Area feet	Maximum Thickness (ft)
1	265	0.1	0	0.7	2.0	0	1.2	800 x 1000	.17
2	265	0.5	0	3.6	2.0	0	1.9	800 x 800	.26
3	265	0.1	30	0.8	2.1	0	1.3	800 x 800	.16
4	265	0.5	30	3.1	2.1	0	1.8	600 x 800	.24
5	265	0.1	50	0.8	2.2	0	1.3	600 x 600	.17
6	265	0.1	70	0.8	2.3	0	1.3	600 x 600	.60
7	265	stratified (0.2 max.)	0	0.6	2.1	0	1.2	800 x 800	.49
22	400	0.1	0	1.1	3.9	0	2.3		

(Source: ADAMEC et al., 1986).

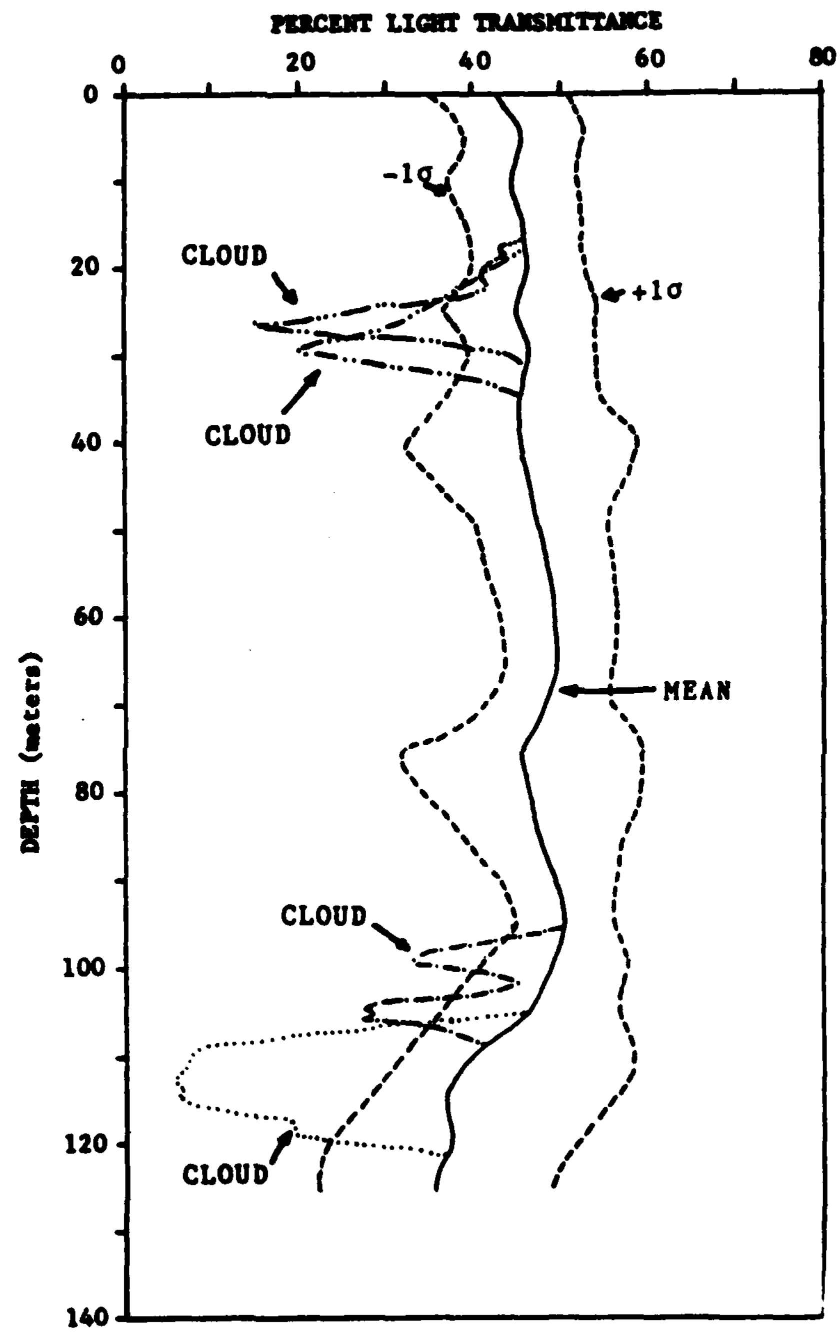


Figure II.7-1 Light transmittance versus depth in the Fourmile Rock disposal area, mean (solid line) and standard deviation (dashed lines) of percent light transmittance. Dotted lines represent depressed light transmittance within selected clouds of suspended sediments. (Source: Schell et al., 1976).

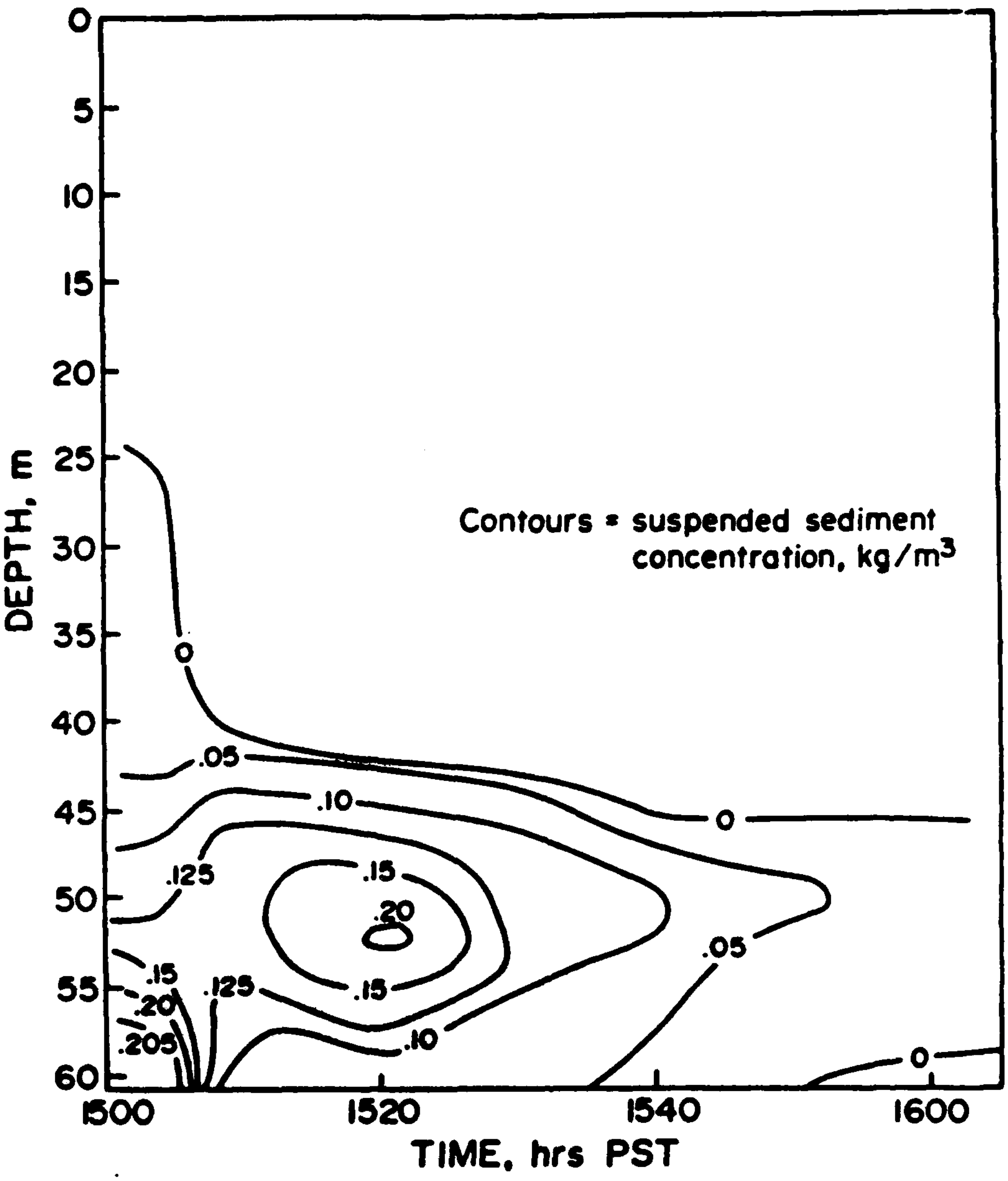


Figure II.7-2 Contour diagram made from transmissometer profiles (10-centimeter path length) and converted to suspended sediment concentration for a 60 minute period starting 20 minutes after the 1440 hour discharge on 24 February 1975. Observing vessel was approximately 26 meters downstream of discharge site. (Source: Bokuniewicz et al., 1978)

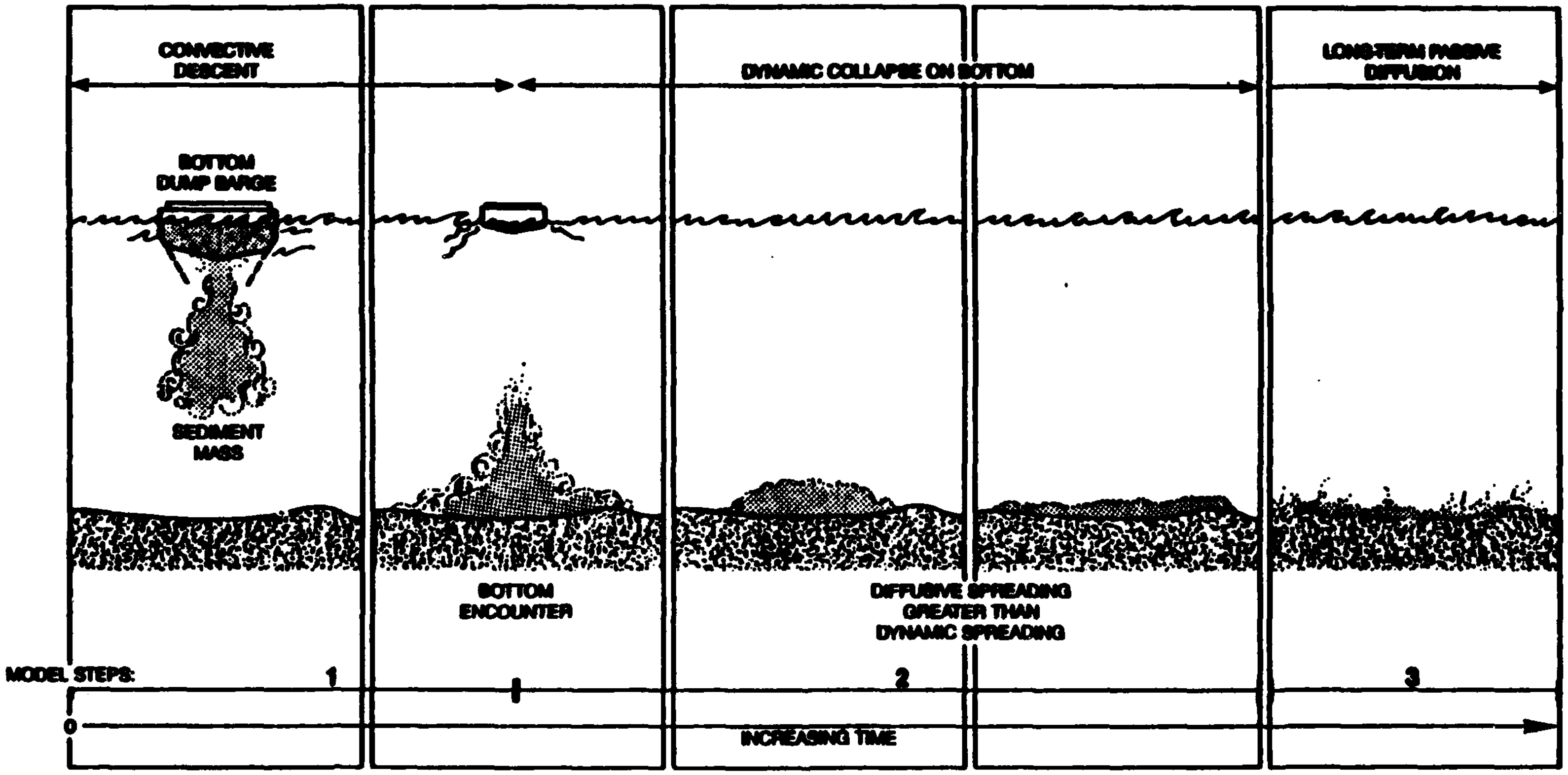


Figure II.7-3 Modeling concept for instantaneous surface release of dredged sediments in deep water.

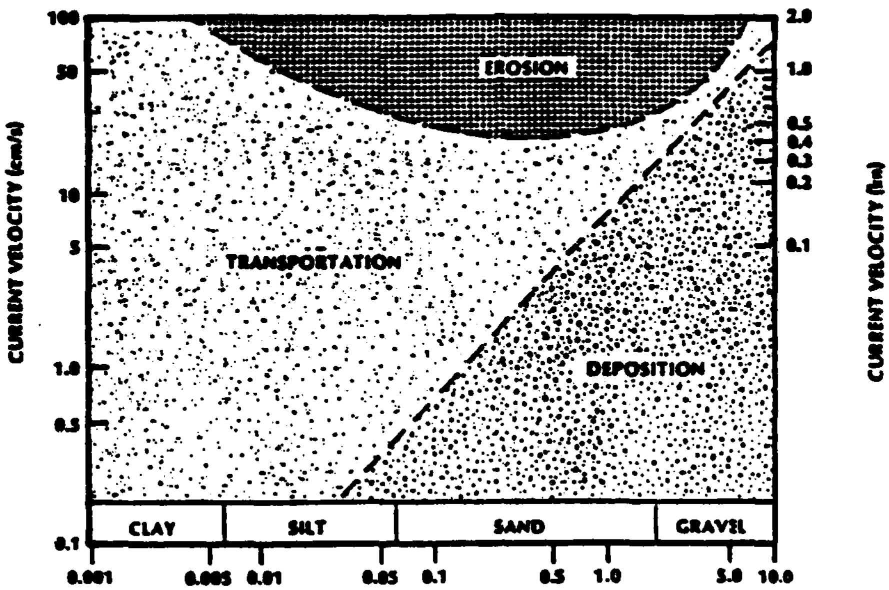


Figure II.7-4 The relationship between current velocity and its potential to deposit, transport, or erode sediments of various grain sizes. (Source: after Moherek, 1978)

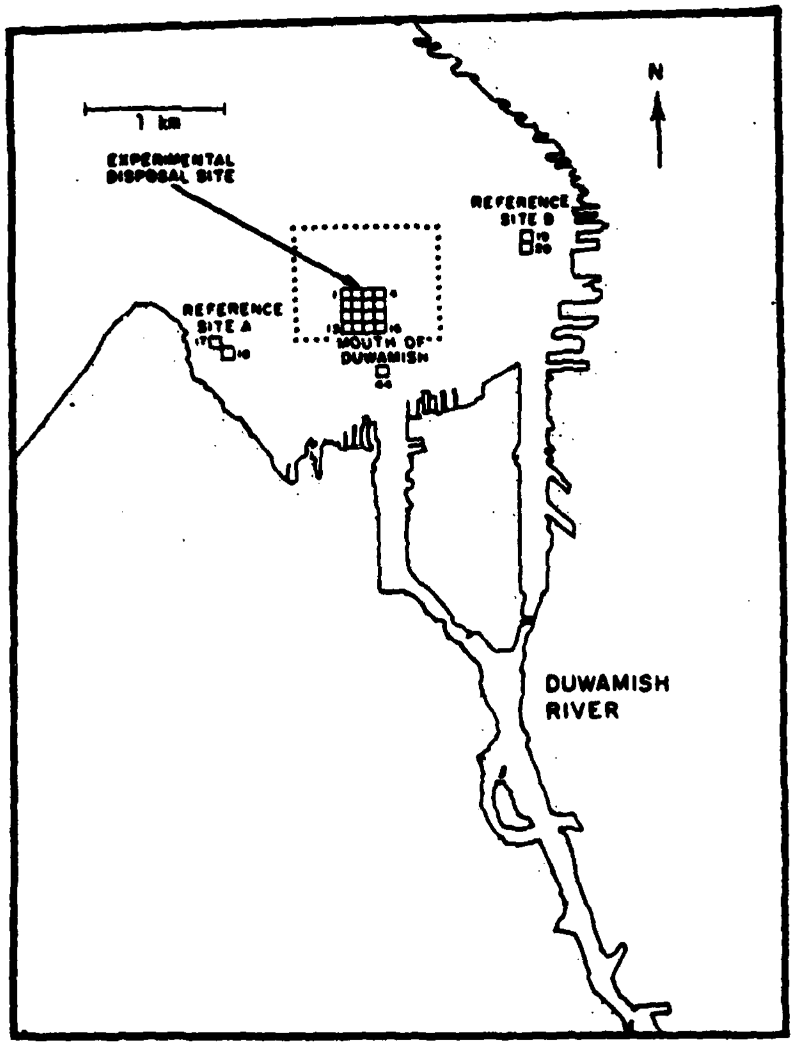


Figure II.7-8 Location of the experimental disposal site in inner Elliott Bay. (Source: Tatem, 1984)

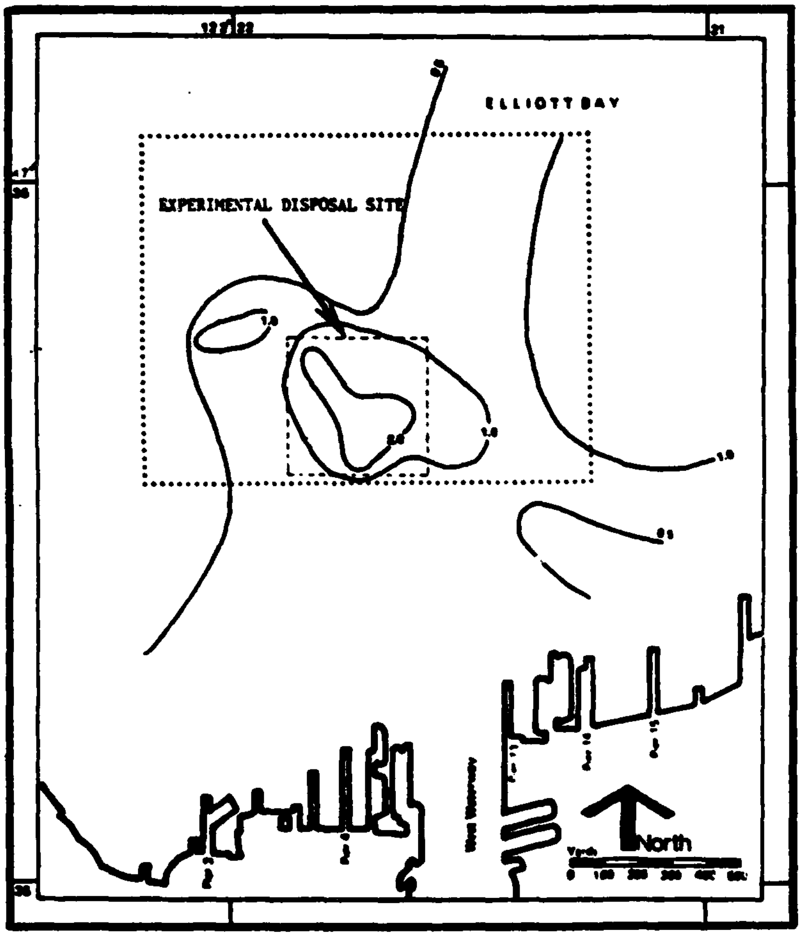


Figure II.7-6 Approximate distribution of total PCB (parts per million) in surface sediments from the February 1979 cruise. (Source: Dexter et al., 1984)

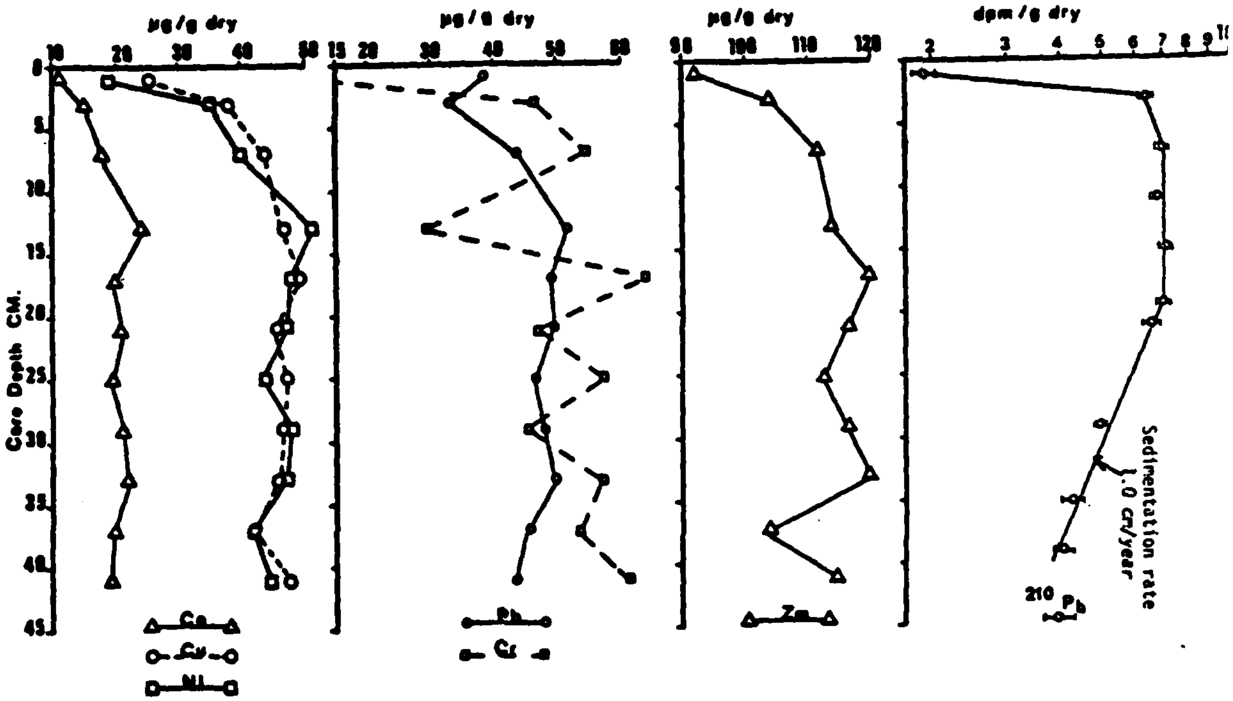


Figure II.7-7 Trace metals and ^{210} Pb concentrations with depth in core 41062 collected at the Fourmile Rock disposal site September 1974. (Source: Schell et al., 1976)

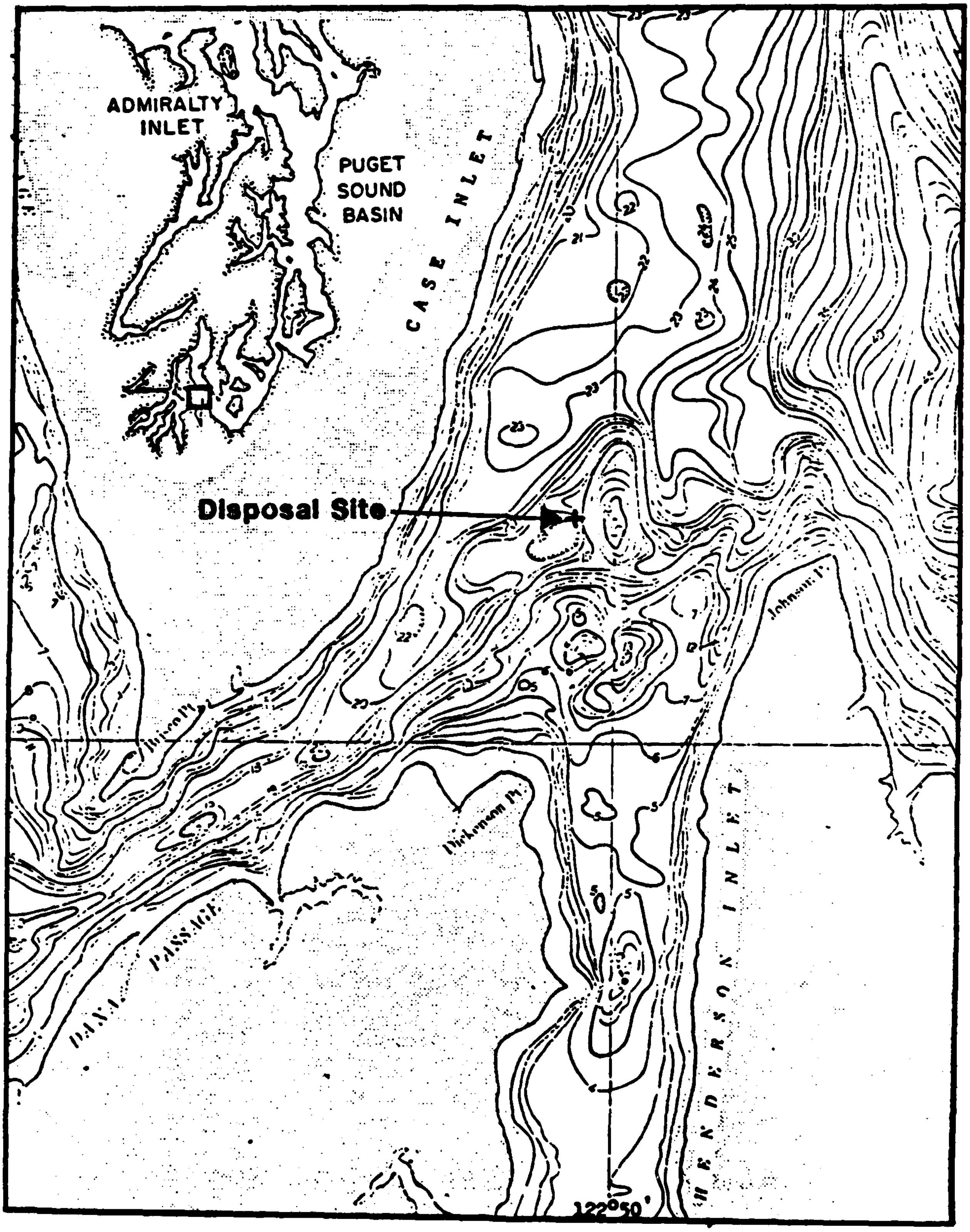


Figure II.7-8 Disposal site (+) in the ebb current direction from Dana Passage. (Source: Sternberg and Collias, 1973)

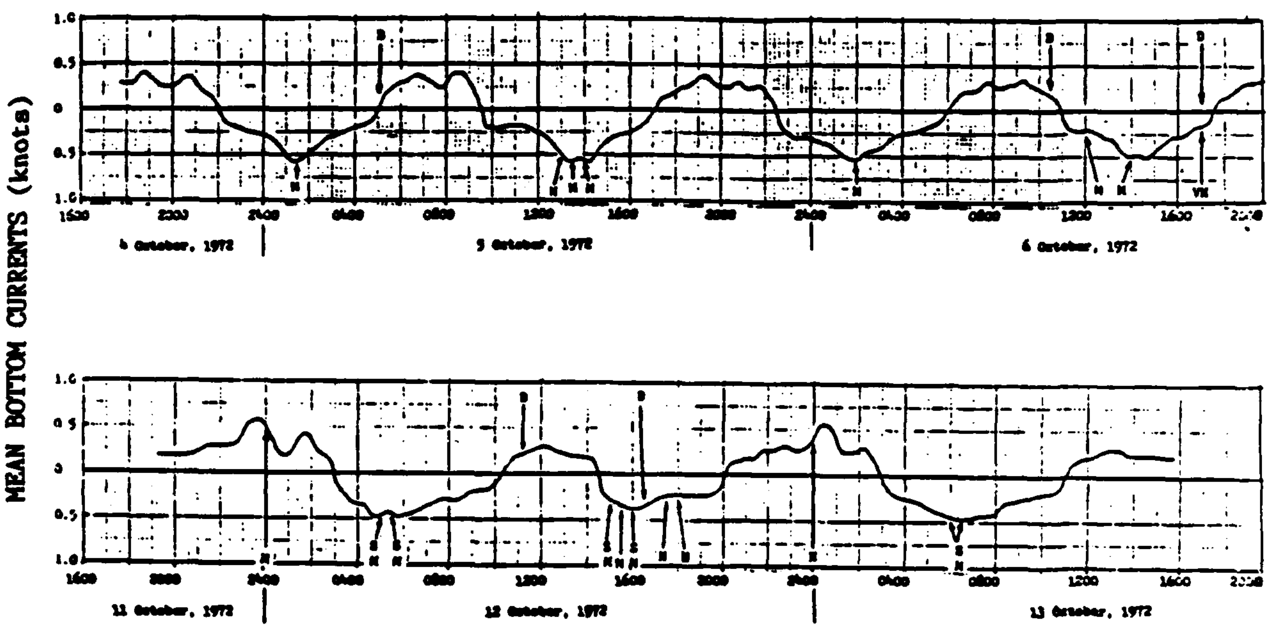


Figure II.7-9 Mean bottom currents (1 meter off the bed) adjacent to the disposal site during two 50-hour sampling periods. (Source: Sternberg and Collias, 1973)

8. BIOLOGICAL RESOURCES: BENTHIC HABITAT/CHARACTERISTICS MAPPED WITH CRAB, SHRIMP, AND BOTTOMFISH ASSESSMENTS

8.1 Objective

The distributions of Dungeness crab, shrimp, and bottomfish were mapped in the ZSFs from data obtained during cruises in February, April (Port Gardner only), June, and September, 1986. The objective was to select disposal sites in areas having a minimal impact on populations of these animals. Based on the data available, disposal in an area with a Dungeness crab density of 100 crab per hectare (or less) is considered a minimum impact area (Cahill, 1986). The data for Port Gardner was obtained through the U.S. Navy homeporting studies, data for the other areas came from PSDDA studies. The following sections are based on reports by Dinnel et al. (1986a-h).

8.2 Background

A key factor in locating PSDDA's disposal sites was an assessment of important fisheries resources including Dungeness crab, shrimp, and bottomfish. Each of these groups is known to use Puget Sound for feeding, growing, and reproducing.

Dungeness crab have been the object of commercial and sports fisheries on the west coast of the United States since 1848 (Dahlstrom and Wild, 1983). With the exception of a few early studies in the 1940's and 1950's, most of the studies specifically designed to understand Dungeness crab have been conducted in the last twenty years. Of these studies, only Mayer (1973) and English (1976) have addressed the locally important crab resources of the inland waters of Puget Sound. Ironically, it is these areas that have experienced some of the greatest increases of urbanization, industrial development, pollution, and fishing pressure.

A historical perspective on Dungeness crab present in Port Gardner during winter is available from previous work by English (1976). Average catches of Dungeness crab for duplicate beam trawls at nine stations, stratified by depth (16-492 feet; English, unpublished data), were:

TABLE II.8-1 HISTORICAL AVERAGE CATCHES OF DUNGENESS CRAB (PER HECTARE).

Date	Male	Female	Total Crab
6 Feb. 1974	10	9	19
5 Feb. 1975	145	30	175
12 Feb. 1976	14	21	35

(Source: T.S. English)

The dramatic and sustained depression of crab resources in the San Francisco Bay area from the early 1960's to the present is a reminder that fishery stocks can be fragile. Although the decline in San Francisco Bay crab stocks may be partially attributable to changing natural oceanographic conditions (Wild et al., 1983), other impacts have been identified which were related to loss of nursery habitats and pollution (Wild and Tasto, 1983; Armstrong, 1983).

Though Dungeness crab are widely distributed in Puget Sound and constitute a commercial fishery of 1.3 to 2.0 million pounds annually (PMFC, 1982), little is known concerning their distribution and habitat preference. Recently Weitkamp et al. (1986) investigated the distribution of Dungeness crab in the shallow waters of Port Gardner. Studies of northern Puget Sound have shown that several life stages also utilize marine areas to depths of 400 feet (Dinnel et al., 1985a). These life stages include growing and molting young and mature adults, females with and without eggs, and possibly mating pairs. The northern Puget Sound data also suggest that certain habitats attract aggregations of crab for unknown reasons, although studies of coastal estuaries indicate a strong dependence of small juveniles on habitat (Armstrong and Gunderson, 1985). Therefore, an assessment of the disposal sites was necessary to determine if these areas are used by crab.

A critical concern during PSDDA was the level at which animal populations become important. This concern is difficult to address; it is a complex issue and there is a general lack of baseline information needed to interpret the available data.

After a review of available data, D. Armstrong and P. Dinnel (personal communications) determined that the average background concentration of crab populations was approximately 10 crab per 1000 square meters in the northern Puget Sound area. They found that there probably will not be a time or place where there will be no crab. Therefore, future dredge disposal operations will inevitably have some impact on crab populations.

However, on a tentative basis, average crab densities of ten or less per 1000 square meters is considered minimal. Since there are 10,000 square meters per hectare, areas having less than 100 crab per hectare were considered to have minimal populations as indicated by Cahill (1986).

Prior to PSDDA the extent of commercial or recreational shrimp resources in the ZSFs was unknown, although no commercial shrimp fishing occurs in or near the ZSFs. It will be shown in this section that the PSDDA work gave considerable assurance that dredged material would be deposited in areas having relatively low populations. Table II.8-2 provides an estimate of average shrimp catches from otter trawls in selected areas of Hood Canal and Puget Sound in and near historical commercial shrimp activity areas.

A variety of bottomfish species of commercial and recreational importance are known to inhabit Puget Sound (English, 1976; Miller and Borton, 1980), and a commercial trawl fishery for bottomfish is known to exist in Saratoga Passage. A recent study has shown that fish species diversity can be large between depths of 150 to 300 feet in Puget Sound (Donnelly et al., 1984).

8.3 Rationale

The reasons for evaluating these biological resources relative to dredged material disposal are two-fold: 1) a favored substrate type may be altered; and 2) food resources may be affected (see also section II.9). It is also important to document the presence and/or absence of crab, shrimp, and bottomfish and their relative abundance compared to other areas. Dungeness crab, for instance, have been shown to aggregate in certain areas relative to size, molting, and egg-bearing (Armstrong et al., 1986), some of these areas being deep-water habitats (Dinnel et al., 1985a). Selection of these habitats may be partially dependent on substrate type for food or for burial to avoid predation, especially during molting or egg-carrying. Changes in sediment quality may reduce the suitability for these purposes. There is some concern about depositing mud on a sandy bottom and less concern about depositing mud on a muddy bottom. In general the preferred approach was to deposit dredged materials on the bottom where there was comparable sediment.

8.4 Methods

This section describes the methods and materials used in the field sampling for crab, shrimp, and bottomfish. The dates and locations of sampling are given in Table II.8-3.

8.4.1 Dungeness Crab Sampling--

Dungeness crab were sampled with a three meter beam trawl described by Gunderson et al. (1985) and used elsewhere in Puget Sound (Dinnel et al., 1985a, 1985b; Weitkamp et al., 1986). The beam trawl was towed approximately 232 meters at a ground speed of 1.5 to 2.0 knots, yielding an area swept by the net of 534 square meters based on an opening of 2.3 meters. All crab caught were measured, their sex determined, their molt condition assessed, and their reproductive condition determined (females with or without eggs); and they were then returned to the water. Incidental catches of bottomfish from the beam trawls were preserved for later processing onshore which included species identification, measurements for length and biomass, and obvious external lesions or parasites.

8.4.2 Bottomfish Sampling--

Bottomfish were sampled with a 7.6-meter otter trawl described by Mearns and Allen (1978). The otter trawl stations were subsets of the beam trawl stations. The otter trawl was towed approximately 370 meters at a ground speed of 2.5 to 3.0 knots, yielding an area swept by the net of 2,220 square meters based on an opening of six meters. Bottomfish were frozen for later processing ashore, which included identification of species, measurement of length and biomass, and checks for external lesions and parasites. Crab caught by the otter trawl were processed aboard the vessel as described above and returned to the water.

8.4.3 Shrimp Sampling--

Shrimp were collected as incidental catches from both the beam trawls for crab and the otter trawls for bottomfish. Specific stations for shrimp sampling were not established. Shrimp were preserved for later processing ashore which included identification of commercially important species, measurement of carapace length, and state of reproduction (females with or without eggs).

8.4.4 Trawl Gear Efficiency--

The otter trawls used for bottomfish also sampled crab, but were about 15 times less efficient than the beam trawl for sampling crab. Comparative average densities of Dungeness crab at three sites in Port Gardner, by season and trawl type, are shown in Figure II.8-1.

Relative shrimp densities at these three sites also depends on the type of gear. Neither trawl type showed a superiority for catching shrimp (Fig. II.8-2). However, the otter trawl caught more shrimp than the beam trawl during approximately two out of three trawls. Since the otter trawling was conducted at selected beam trawl stations during June/July and September, a complete otter trawl data set is not available. Therefore, beam trawl data was mapped for shrimp.

Density is defined as the number of animals per unit of area estimated from the beam or otter trawl catches. Bottom trawls are rarely 100% efficient sampling devices, the actual fishing efficiency being dependent on a variety of variables including gear type, tow speed, bottom conditions, and animal species. Hence, the term density is used with the understanding that the actual population densities are probably underestimated in most cases.

8.4.5 Sample Sites--

Sampling was conducted in the vicinity of preliminary disposal sites in the four ZSFs: Saratoga Passage; Port Gardner; Elliott Bay; and Commencement Bay. See Dinnel et al. (1986a-h) for a detailed description of the sampling locations.

8.5 Distribution of Crab in the ZSFs

Maps of crab abundance were prepared for each ZSF based on sampling done during the winter, spring, summer, and fall of 1986 which are described below.

8.5.1 Port Gardner--

During February, the beam trawl catches of Dungeness crab, especially gravid females, were unexpectedly high throughout a major portion of Port Gardner for stations less than 90 meters (295 feet) deep. In fifty-six trawls over a four-day sampling period, 376 Dungeness crab were caught. The otter trawl also sampled Dungeness crab, but much less effectively than the beam trawl. Eighteen otter trawls caught 34 crab.

Dungeness crab were not evenly distributed throughout Port Gardner, and their distribution varied according to sex and reproductive state for the females. Male crab were found almost exclusively in shallow water areas (Fig. II.8-3A); eighty-five percent were found in water no deeper than 20 meters (66 feet) and 98% in less than 40 meters (131 feet). In contrast, gravid females were distributed to much deeper depths with 73% recovered from depths of 40 meters (131 feet) or

greater, and 16% from depths of 100 to 160 meters (328-525 feet) (Fig. II.8-4A).

The possibility that gravid females might be present at depth was previously suggested by Weitkamp et al. (1986). Gravid females were found in abundance considerably higher than observed previously in deep water areas of northern Puget Sound.

Average crab density in Port Gardner for February 1986 (126 per hectare) compares favorably with the historical data, indicating (albeit at a superficial level) no drastic changes in crab abundances in Port Gardner. Note, however, the high degree of between-year variability in crab catches reported by English. The reasons for these fluctuations are not presently known.

In April the highest crab densities occurred in the eastern, shallower portion of Port Gardner. The distributions of male and female crab throughout Port Gardner are shown in Figures II.8-3B and II.8-4B, respectively. Crab densities were highest in the 0-80 meter (0-262 feet) depth range, with the females preferring the 40-100 meter range, and males being most abundant in shallow water. These figures also show the relative scarcity of males which comprised only 8% of the total catch.

The general distribution of crab in Port Gardner remained essentially unchanged from February to April. Males were scarce (only 7% of total catch) and were caught mostly in shallow water, while females were abundant and preferred depths between 40 and 100 meters (131 - 328 feet). Between February and April, eggs carried by the gravid females hatched. In February, 78% of the females carried eggs (advanced, eyed embryos), while less than 10% still carried eggs in April.

The average density of Dungeness crab calculated from beam trawls in Port Gardner during June was intermediate to the February and April average densities. Both the spatial and depth distributions of Dungeness crab in June were similar to the patterns observed in February and April except that males tended to be slightly deeper on the average. Generally, both male and female crabs were caught along the nearshore slope from Mukilteo to the Snohomish River delta (Figs. II.8-3C and II.8-4C) and continued to be rare in deeper areas (>100 meter depth) of outer Port Gardner. Depthwise, the highest densities of female crab were in the 20 meter to 110 meter range with peak densities at 80 meters. The depth distribution of males was fairly uniform between depths of 10 meters to 100 meters, a change from the two previous seasons where males were rarely caught below 40 meters. Again, males were relatively scarce (9%) compared to the females which comprised 91% of the Dungeness crab catch. Less than 1% of the females were gravid and approximately 4% of both male and female crabs had shells that were either soft or very soft which is indicative of recent molting.

The general distribution and densities of Dungeness crab in Port Gardner remained essentially unchanged in September from the earlier sampling periods except that a few more males were caught in deep water (Fig. II.8-3D). Female crab densities continued to be highest in the 20 to 100 meter range with the highest average densities occurring at 80 meters (Fig. II.8-4D).

8.5.2 Saratoga Passage--

Dungeness crab were not found in the beam trawl samples taken in the ZSF during February (Fig. II.8-5A). One crab each was recovered from the 10 and 80 meter (33 and 262 feet) stations west of the ZSF, and six crab were recovered from the 10-meter (33 feet) station nearest Camano Island. The crab recovered from the 10-meter (33 feet) stations were either males or non-gravid females. The one found at 80 meters (262 feet) was a gravid female with eggs at approximately mid-term.

More crab were caught in Saratoga Passage during the June sampling than during February. However, the distribution of the crab for the two months was quite similar (Figs. II.8-5A and II.8-5B). No crab were caught at the stations in the ZSF or at any of the deep stations north of the ZSF. Dungeness crab were caught only at the shallower stations (10 to 80 meters; 33 - 262 feet depths) both east and west of the ZSF and included both male (25% of total catch) and female (75%) crab. Only one of the 24 female crab caught in June was gravid.

8.5.3 Elliott Bay--

Dungeness crab were absent from all trawls at Fourmile Rock and inner Elliott Bay during February, and only one rock crab (C. gracilis) was recovered. Two male Dungeness crab were caught in June at depths of 10 to 20 meters (33 to 66 feet) on the north side of Duwamish Head (Fig. II.8-6). Occasionally rock crab were caught at the shallower stations. Dungeness crab were absent from all trawls at Fourmile Rock and inner Elliott Bay during September.

8.5.4 Commencement Bay--

The only crab caught in the beam trawls were purple crab (one each in February and June at 10 meters (33 feet)) and red rock crab (six in June at 10 to 40 meters or 33 to 131 feet). Crab were absent from the otter trawls made in Commencement Bay. No crab were caught in September.

8.6 Distribution of Shrimp in the ZSFs

Shrimp were generally more effectively caught with the otter trawl than with the beam trawl. The available data is primarily beam trawl data and is therefore the data that is presented for discussion. For comparison, the otter trawl has shown shrimp densities as much as eleven times greater than densities from the beam trawl. When available, otter trawl densities have been shown. Table II.8-4 provides data on average shrimp catches, lengths, and weights, by species for shrimp caught by otter trawl in the proposed PSDDA sites.

8.6.1 Port Gardner--

In February the quantity of shrimp was found to be greatest at intermediate depths where very few were found in shallow water (Fig. II.8-7A). Small catches of pink shrimp (Pandalus jordani or P. borealis) were common in the deeper areas, while coon-striped (P. danae), spot prawns (P. platyceros), and side-stripe (Pandalopsis dispar) increased in number in the 80 to 150 meter (263 to 492 feet) range. Shrimp were caught in 38 of the 56 beam trawls. The highest abundance occurred in the 40 to 100 meter (131 to 328 feet) depth interval. In April shrimp were caught at 26 of the 55 beam trawl stations (Fig. II.8-7B). The shrimp distribution was restricted primarily to the deeper stations although abundances were generally lower than observed during other seasons. A graph of shrimp density versus depth shows the highest abundance below 100 meters (328 feet; Fig. II.8-8).

Shrimp were caught at 19 of the 55 beam trawl stations during June. Shrimp sampled by the beam trawl were most abundant in depths of 40 to 80 meters off Mukilteo and were primarily spot prawns (Pandalus platyceros) followed by side-stripe (Pandalopsis dispar) and pink (Pandalus spp.) shrimp offshore of the East Waterway (Fig. II.8-7C). As a function of depth, shrimp were most abundant at the 40 meter depth, a change from both February and April when shrimp were most abundant at 80 and 100 meters, respectively (Fig. II.8-8).

Average shrimp densities for June remained depressed (30 shrimp per hectare) as compared to the February densities of 123 shrimp per hectare but were slightly increased from the 19 shrimp per hectare observed during April. The highest shrimp densities in June again occurred off Mukilteo (spot prawns) between 40 and 80 meter depths.

The data for September (Fig. II.8-7D) show shrimp abundance to be increased over the previous seasons. The average shrimp densities for September otter trawl is equal to the February density of 123 shrimp per hectare, but is less than half of the beam trawl catch of 269 shrimp per hectare.

Shrimp densities were substantially higher in September than during the three previous seasons. Shrimp densities show a pattern very similar to crab with the highest densities along the inshore slope between depths of 40 to 100 meters (131 - 328 feet) with substantially reduced densities at or below 110 meters (Fig. II.8-7D). Thus, with the disposal sites in much deeper water, there should be no significant impact on shrimp.

8.6.2 Saratoga Passage--

The average densities of beam trawl caught shrimp (all species combined) at the ZSF were 50 shrimp per hectare in February and 62 shrimp per hectare in June (Figs. II.8-9A and II.8-9B). The average densities for all stations in Saratoga Passage in February and June were 37 and 56 shrimp per hectare, respectively. These differences in seasonal densities are probably not significantly different since the shrimp catches were highly variable between stations. In general, the highest densities of shrimp were in deep water (80 to 120 meters or 263 to 394 feet). These densities are low when compared to other areas of Puget Sound.

8.6.3 Elliott Bay--

Average densities of shrimp calculated from the beam trawl catches were highest in February at the inner bay ZSF (299 shrimp per hectare) as compared to the Fourmile Rock ZSF (44 shrimp per hectare; Fig. II.8-10A). This pattern was reversed in June (Fig. II.8-10B). In general, shrimp densities were highest at the deepest stations except for a relatively large catch of coonstriped shrimp (Pandalus danae) in February at the 10 meter (33 feet) depth inshore of the Fourmile Rock ZSF.

Uniformly low (150 shrimp per hectare) estimated densities of shrimp were encountered at all beam trawl stations in Elliott Bay except two stations in inner Elliott Bay (Fig. II.8-10C). The species composition of shrimp in this area favored pink shrimp (Pandalus borealis) with a few of the larger spot prawn (Pandalus platyceros) and side-stripe shrimp (Pandalopsis dispar) in evidence. The average densities of shrimp at both ZSFs were 322 and 44 shrimp per hectare with an overall average for all Elliott Bay beam trawl samples of 135 shrimp per hectare.

The otter trawl was more efficient than the beam trawl at catching shrimp in Elliott Bay during September. The average estimated shrimp density for Elliott Bay as calculated from the otter trawl catches was 540 shrimp per hectare versus 246 shrimp/ hectare for the same subset of beam trawls. However, the same realtive density pattern was observed between the two

proposed disposal sites. Inner Elliott Bay (885 shrimp per hectare) had ten-fold more shrimp than Fourmile Rock (80 shrimp per hectare).

8.6.4 Commencement Bay--

Shrimp were in relatively low abundance during February, showing slight increases in inner Commencement Bay (Fig. II.8-11A). The density of June catches were roughly half that of February (Fig. II.8-11B). The distribution of shrimp was generally uniform in February while shrimp tended to be most abundant at the preliminary disposal sites in June.

Calculated densities of shrimp at the beam trawl stations for September were all less than 150 shrimp per hectare with the exception of two stations located off Browns Point (Fig. II. 8-11C). The highest density of shrimp occurred at the 10 meter depth station off Browns Point. This station had a calculated density of 1,067 shrimp per hectare, all of which were juvenile coonstripe shrimp, Pandalus danae. The Browns Point 80 meter station had the second highest shrimp density of 281 shrimp per hectare, all of which were pink shrimp, P. borealis. The calculated average densities of shrimp at the two priority PSDDA disposal sites were 67 and 81 shrimp per hectare at Sites 1A and 2A, respectively. Overall the average density of shrimp from all beam trawl stations was 117 shrimp per hectare.

The otter trawl was again more efficient at sampling shrimp in Commencement Bay when compared to the beam trawl. The average shrimp densities for six stations (PSDDA Site 1A and 2A stations) trawled by both gear were 466 and 79 shrimp per hectare for the otter and beam trawls, respectively. The otter trawls showed no substantial difference between these PSDDA sites.

8.7 Distribution of Bottomfish in the ZSFs

8.7.1 Port Gardner--

Bottomfish were moderately abundant at the PSDDA 2 site and least abundant at the PSDDA 1 disposal site. This pattern remained the same during all sampling periods, with biomass increasing each season.

The most abundant fish (English sole, Parophrys vetulus; Dover sole, Microstomus pacificus; slender sole, Lyopsetta exilis; Pacific hake, Merluccius productus; and ratfish, Hydrolagus colliei) remained the same during all four sampling periods; however, abundances fell from February to April and rose in some cases in July and September. The relative abundance

of Pacific hake was high for all four sample periods, but the biomass declined markedly from February to April and rose only slightly in July and again in September. Thus, only smaller (possibly young-of-the-year) individuals were present during April, July, and September. A nearby area (Port Susan) is known to be a spawning ground for Pacific hake and supports a commercial hake fishery.

A comparison of September, June, April, and February sampling showed that PSDDA 2 had 81, 156, 102, and 401 fish per hectare, while PSDDA 1 had 108, 60, 68, and 403 fish per hectare, respectively. The number of species caught at the PSDDA Sites 1 and 2 which showed marked reductions from February to April and July (16 and 11 in February, down to 7 for both in April and 6 for both in July) rose in September to 10 and 11, respectively.

Biomass generally followed the same pattern as abundances PSDDA 2 (15 kg/ha) and PSDDA 1 (11 kg/ha). This was the same pattern exhibited previously except that absolute biomass fell during April and July, then rose slightly in September.

Comparison sampling of the otter trawl and beam trawl indicated that the otter trawl was clearly a better sampler of bottomfish than the beam trawl as measured by species diversity, abundance, biomass, and range of size categories sampled. However, the beam trawl provides good complementary data on juvenile fish.

Internal and external gross examination of flatfishes for fin erosion, tumors, parasites and liver abnormalities indicated insignificant indices of these conditions.

8.7.2 Saratoga Passage--

Only one sample cruise (July 1) was conducted for bottomfish in Saratoga Passage. The total abundance values ranged from 2 to 19 individuals per station, while total biomass values ranged from 137 grams to 3,468 grams per station (Figs. II.8-12A,C). The PSDDA site had an intermediate abundance value and had the highest biomass value. The dominant species included ratfish, English sole, Dover sole, slender sole, and adult Pacific hake. Pacific hake were found in the deeper PSDDA site and the reference stations, but not in the shallower locations. In contrast, English sole were only found in the shallower locations. Dover sole were confined to the 40 meter west station. Ratfish and slender sole occurred at the deeper (PSDDA) stations and intermediate depths (Figs. II.8-12B,D). No evidence of blood worms, liver tumors, skin tumors or fin erosion was found in Saratoga Passage.

8.7.3 Elliott Bay—

The results of fish sampling in Elliott Bay reveal that the proposed disposal sites generally have higher values of abundance, biomass, and species richness than their corresponding reference stations. The Fourmile Rock site and the adjacent reference stations exhibited a pattern much like inner Elliott Bay: summer season abundance, biomass, and species richness figures were comparable, whereas the autumn values of biomass and species richness for Fourmile Rock exceeded the reference stations. Species diversity did not show any clear pattern.

Fourmile Rock samples were taken in close proximity to samples collected for the Renton Sewage Treatment Plant Project (Stober and Chew, 1984). The earlier study found biomass values higher at the deeper sites in contrast to the present study. Fourmile Rock had higher biomass values than the deeper reference stations. This would suggest that Fourmile Rock would have higher species richness and species diversity values than the Fourmile Rock reference stations. Indeed, Fourmile Rock values were either comparable to, or exceeded, the reference station values for species richness and species diversity. Neither study was conducted during all four seasons, thus results from this study should not be considered indicative of conditions at the sample sites throughout the year.

The inner Elliott Bay site was compared with a report on the effects of dredged material disposal on benthic invertebrates in inner Elliott Bay (Bingham, 1978). The 1978 report found no substantial difference in infaunal (invertebrate) species richness or biomass, but did find that the shallower stations had the greatest species richness and biomass. The same observation was made at the inner Elliott Bay site (for fish) where the deeper reference station had lower species richness and biomass. Neither Bingham (1978) nor this study found any clear trend in species diversity versus depth.

Fish health was generally good. Blood worm infection in English sole was the only disease noted. Fin erosion, skin tumors and liver tumors have been found in Elliott Bay, but typically near the inner developed shore and the Duwamish River (Malins et al., 1982). The present study sites were located in the deeper regions away from the shore of Elliott Bay and may explain why the disease incidence was found to be lower than at previous inshore sampling locations.

The abundance values ranged from 17 to 248 fish per station, while the biomass values ranged from 2,800 to 20,630 grams per station (Figs. II.8-13A and II.8-14A). The summer abundance values were lower (17 to 66 fish per station) than the autumn values (30 to 248 fish per station). Biomass showed a similar pattern to abundance, summer values were generally lower

than corresponding autumn values (3,970 to 8,783 and 2,800 to 20,630 grams, respectively).

Six species of fish dominated the catches in Elliott Bay; English sole, Dover sole, Pacific hake, slender sole, ratfish and blackbelly eelpout. Not every species was found at each site (Figs. II.8-13A,B and II.8-14A,B). The inner Elliott Bay site was the shallowest and had the largest abundance and biomass of Pacific hake, slender sole, and blackbelly eelpout. Fourmile Rock had the largest abundance and biomass of English sole, Dover sole, and ratfish, while the other species declined. Fourmile Rock had lower abundance and biomass values compared with the values found at the adjacent reference stations. Generally, abundance and biomass values increased from the summer to the autumn sampling. Indeed, English sole, Dover sole, and ratfish abundance and biomass values increased many fold. The shallower inner Elliott Bay area had greater numbers of the smaller fishes such as blackbelly eelpouts and slender sole in contrast to the deeper Fourmile Rock area where the larger species dominated.

English sole, Dover sole, and flathead sole showed evidence of blood worm infections. Incidence in these three species ranged from 0% to 42%. Fourmile Rock had the highest incidence of blood worm infection in English sole and Dover sole with flathead sole showing only a minor incidence. There were no indications of liver tumors, skin tumors, or fin erosion.

The case for the Elliott Bay PSDDA sites is less clear. The inner Elliott Bay site had greater abundance, biomass, and species richness than the associated reference station. However, most of the fish species that would be impacted at the inner Elliott Bay site have no direct commercial or recreational value. In contrast, some of the species found in abundance at Fourmile Rock are of commercial and recreational value.

8.7.4 Commencement Bay—

Several trawling studies have previously been conducted in Commencement Bay. These studies concentrated their efforts in the nearshore areas (Becker, 1984; Weitkamp and Schadt, 1981; Tetra Tech, 1985) and in the inner part of Commencement Bay (e.g., the old flood channels of the Puyallup Rover (Malins et al., 1982; Tetra Tech, 1985c; Weitkamp and Schadt, 1981). Becker (1984) and Tetra Tech (1985c) used the same otter trawl as the present study; however, sampling depths only reached 32 meters in contrast to the 175 meter depths of the proposed PSDDA sites. Weitkamp and Schadt (1981) used a different (smaller) otter trawl and again only sampled the shaller and inner Commencement Bay areas.

Data from Commencement Bay indicate that three of the four indices of site utilization by fish varied inversely with depth. As depth increased, species richness, total abundance and total biomass decreased. No correlation between depth and species diversity was evident. However, Tetra Tech (1985c) found the species diversity on the inner harbor waterways to be much higher (3.5) compared to the present study. Results of this PSDDA study suggest higher catches occurring in deeper water during autumn, and Weitkamp and Schadt (1981) found that abundance in the shallower areas was highest in summer and lower during other seasons of the year. Becker (1984) found that Dover sole were located at deeper stations while English sole were typically found in shallower waters, similar to the findings of this PSDDA study.

Fish health was generally good for the flatfish caught in Commencement Bay during this study. The only disease found was blood worm infection in English sole. Incidence for this disease reached 100% at some stations, but the sample sizes were very small (less than five individuals per sample) for locations with high incidence rates. Tetra Tech (1985) found incidences of liver tumors (3.3%) and fin erosion (0.9%), and Malins et al. (1982) also found liver tumors and skin tumors in the inner (shallow) portions of Commencement Bay in areas known to be contaminated with industrial wastes.

Environmental measurements were only available for the autumn period. Dissolved oxygen, temperature, salinity and Secchi disc measurements were all within the ranges found in other parts of Puget Sound (Stober and Chew, 1984).

The proposed PSDDA sites have the greatest depth and the lowest abundance, biomass and species richness measures of the stations sampled during this study. This suggests that disposal of dredged material at the proposed disposal sites would have a relatively low impact on fish assemblages. Total abundance values ranged from 3.5 fish per station to a high of 307 fish per station. Total biomass values ranged from 2,052 grams to a high of 36,929 grams per station. The summer values were lower than the autumn values and the deeper stations, which included the PSDDA sites, had the lowest values regardless of season. Total abundance and biomass values were highest at 40 meters then declined at 20 meters (Figs. II.8-15A and II.8-16A). Three species of fish: English sole, Dover sole, and ratfish were found in most samples. Generally, the PSDDA sites contained the lowest abundance and biomass of these three species when compared to the samples collected outside the PSDDA sites. English sole abundance and biomass were the greatest at 40 meters in both early summer and autumn, followed by summer catches at 20 meters. At the deeper stations, including the PSDDA sites, the English sole abundance and biomass values were very low (Figs. II.8-15A,B and II.8-16A,B). The abundance and biomass of Dover sole and ratfish were greater than English sole at the deeper stations. When the deeper stations were taken as a group, the PSDDA sites had the lowest abundance and biomass values.

English sole, Dover sole, rex sole, and rock sole all showed indications of blood worm infections. Incidences ranged from 0% to 100%. English sole had consistently high infection rates, often as high as 100%, although the sample sizes associated with the highest incidence rates were less than 5 fish each. Incidence of liver tumors, skin tumors and fin erosion were all 0%.

The fish ecology data for Commencement Bay would suggest that the two proposed disposal sites are probably acceptable for disposal of uncontaminated dredged material. The numbers of fish were low at these sites and it would appear that little impact would occur to the fish assemblage.

TABLE II.8-2 ESTIMATED AVERAGE SHRIMP CATCHES PER HECTARE FROM OTTER TRAWLS CONDUCTED IN SELECTED AREAS OF HOOD CANAL AND PUGET SOUND FROM 1967 TO 1979. THESE ESTIMATES ARE DERIVED FROM UNPUBLISHED DATA COLLECTED AND SUMMARIZED BY DR. KENNETH CHEW, SCHOOL OF FISHERIES, UNIVERSITY OF WASHINGTON.

Location/Depth (m)	Number of trawls	Catch (kg)/Ha
HOOD CANAL		
Dabob Bay		
20 - 45	33	2.9
45 - 70	26	2.7
70 - 125	24	3.5
Pleasant Harbor		
35 - 65	5	2.9
65 - 90	8	10.0
Seabeck		
45 - 80	3	0.8
Potlatch		
70 - 90	4	6.8
PUGET SOUND		
Port Susan		
25 - 70	9	12.8
80 - 120	7	5.7
Tulalip		
50 - 80	3	13.5
80 - 120	4	11.8
Carr Inlet		
45 - 80	4	15.1
80 - 135	3	2.4

TABLE II.8-3 DATES AND LOCATIONS OF SAMPLING FOR CRAB, SHRIMP, AND BOTTOMFISH.

Location	Sampling dates in 1986	
	Beam Trawl	Otter Trawl
Saratoga Passage	February 11	
	June 10	July 1
Port Gardner	February	
	April	
	June	June
	September 12,17,18	September 11,15
Elliott Bay	February 14	
	June 11	July 3
	September 4	September 9
Commencement Bay	February 18	
	June 12	June 13
	September 5	September 8

Table II.8-4 Average shrimp catches, lengths and weights for all shrimp caught by otter trawl in the proposed disposal sites in Saratoga Passage, Elliott Bay and Commencement Bay during June and September (combined), and Port Gardner during February, April, June, and September (combined) 1986.

SPECIES	SARATOGA PASSAGE	PORT GARDNER	ELLIOTT BAY	COMMENCEMENT BAY
Spot Prawn				
Ave. #/Ha	0	0.8	23.2	1.5
Ave. carapace length (mm)	-	19.0	33.6	26.8
Ave. weight (g)/shrimp	0	5.0	23.0	12.0
Total weight (kg)/Ha	0	0.0	0.53	0.02
Sidestripe				
Ave. #/Ha	54.1	6.2	23.2	53.3
Ave. carapace length (mm)	23.2	18.0	23.0	15.3
Ave. weight (g)/shrimp	6.2	3.0	6.0	1.9
Total weight (kg)/Ha	0.33	0.02	0.14	0.10
Smooth Pink				
Ave. #/Ha	0	0.0	23.9	0.8
Ave. carapace length (mm)	-	- -	16.9	16.5
Ave. weight (g)/shrimp	0	0.0	3.4	3.1
Total weight (kg)/Ha	0	0.0	0.08	0.0
Pink				
Ave. #/Ha	72.1	17.2	260.6	306.4
Ave. carapace length (mm)	16.5	14.4	16.8	17.2
Ave. weight (g)/shrimp	3.2	2.5	3.5	3.6
Total weight (kg)/Ha	0.23	0.04	0.91	1.1
Humpback				
Ave. #/Ha	0	0.0	2.4	0
Ave. carapace length (mm)	-	- -	26.4	-
Ave. weight (g)/shrimp	0	0.0	12.0	0
Total weight (kg)/Ha	0	0.0	0.03	0
All Species Combined				
Ave. #/Ha	126.2	24.2	333.3	362.0
Total weight (kg)/Ha	0.56	0.1	1.69	1.22

* Port Gardner data is preliminary.

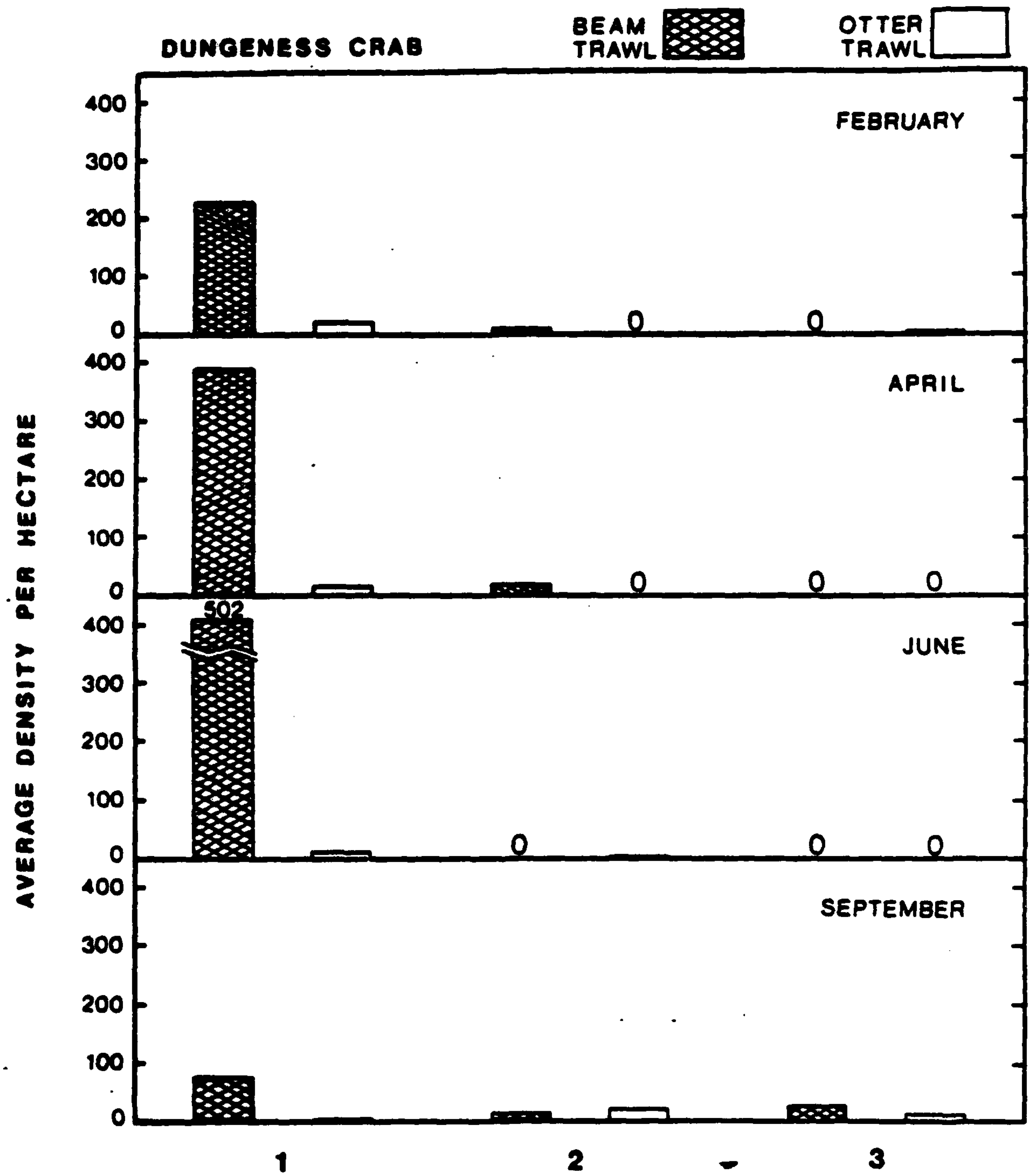


Figure II.8-1 Trawl gear efficiency for crab in Port Gardner. (Source: adapted from Dinnel et al., 1986d)

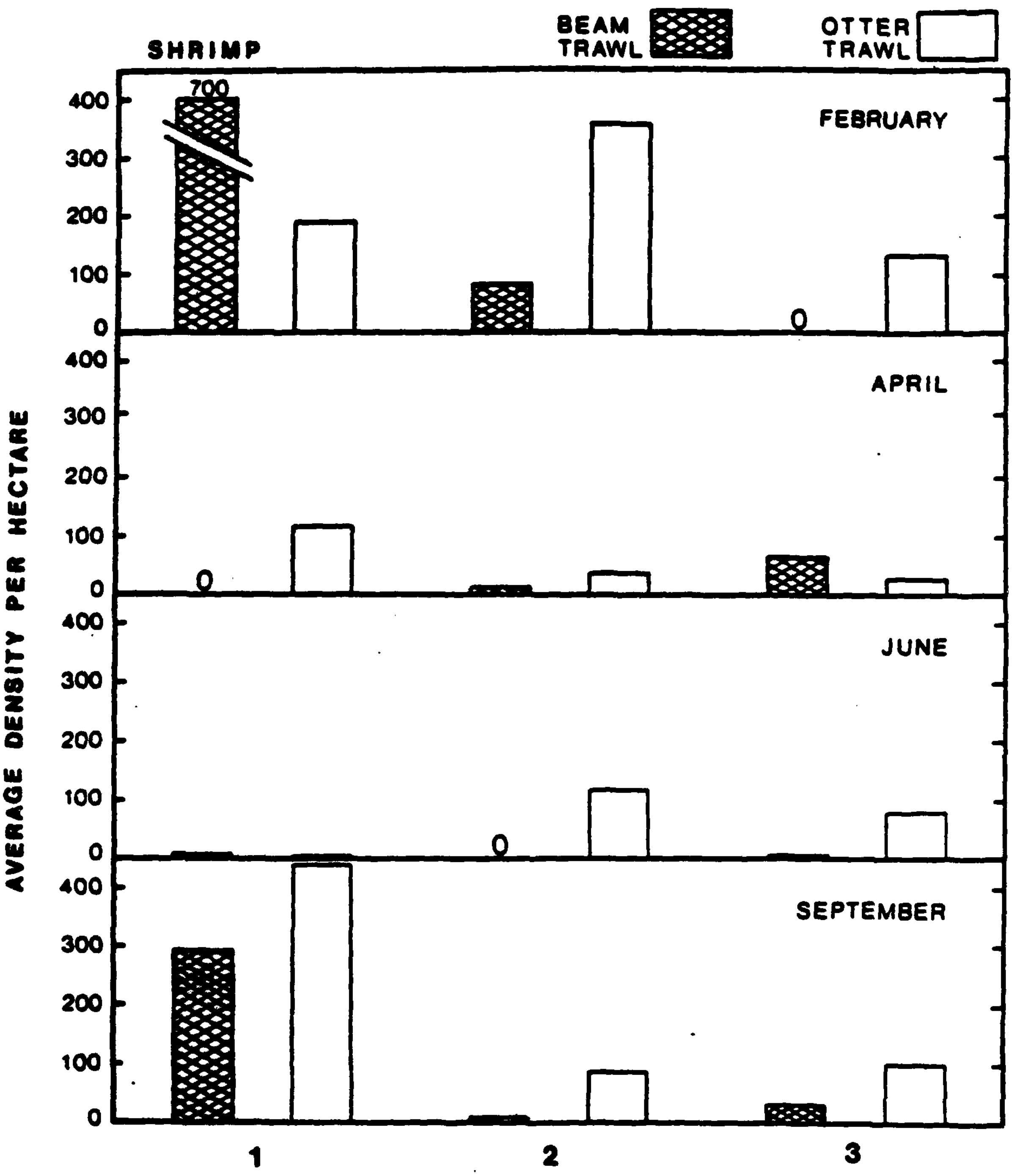


Figure II.8-2 Trawl gear efficiency for shrimp in Port Gardner. (Source: adapted from Dinnel et al., 1986d)

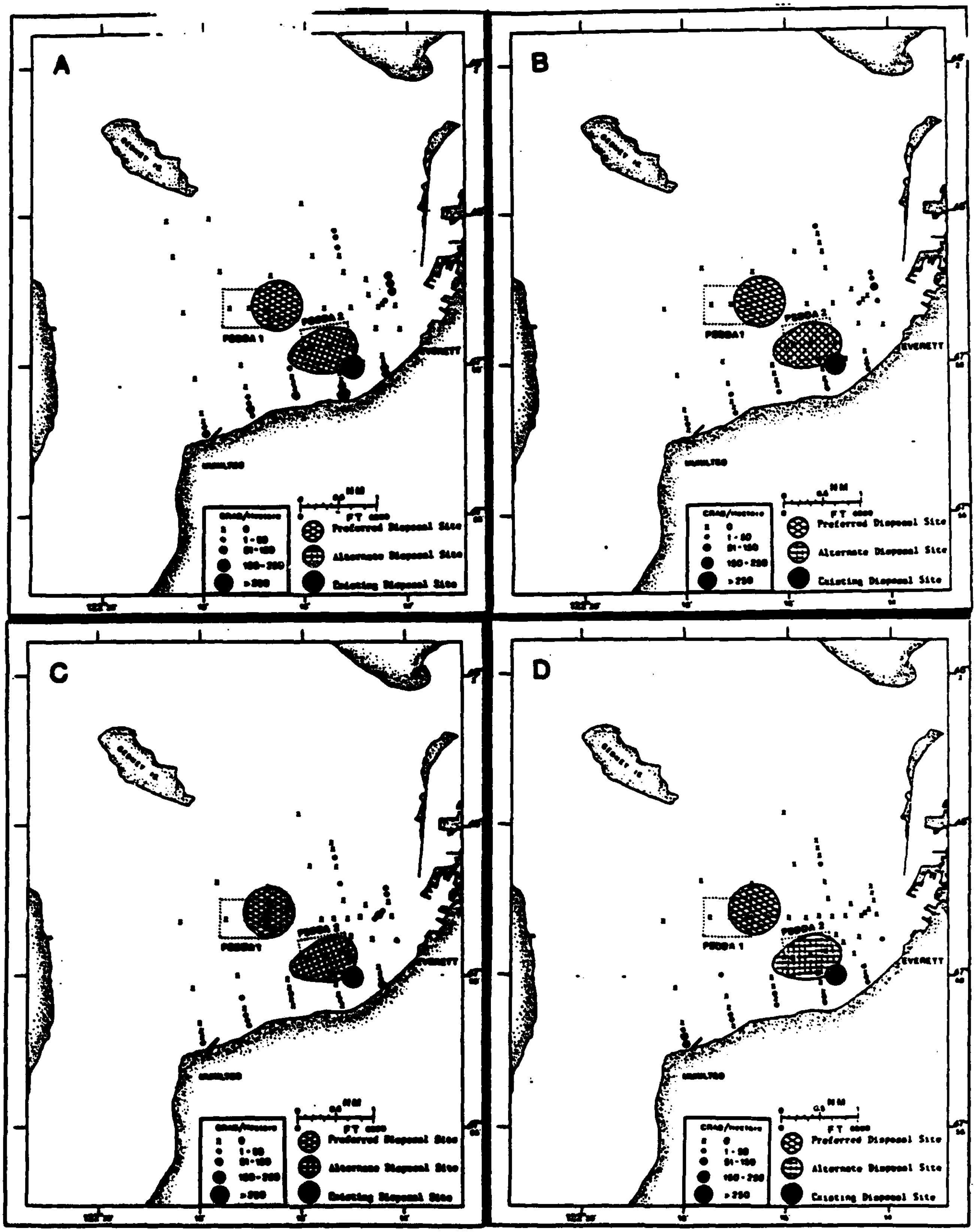


Figure II.8-3 Port Gardner male crab density for: A) February, B) April, C) June, and D) September 1986; beam trawl (Source: adapted from Dinnel et al., 1986i)

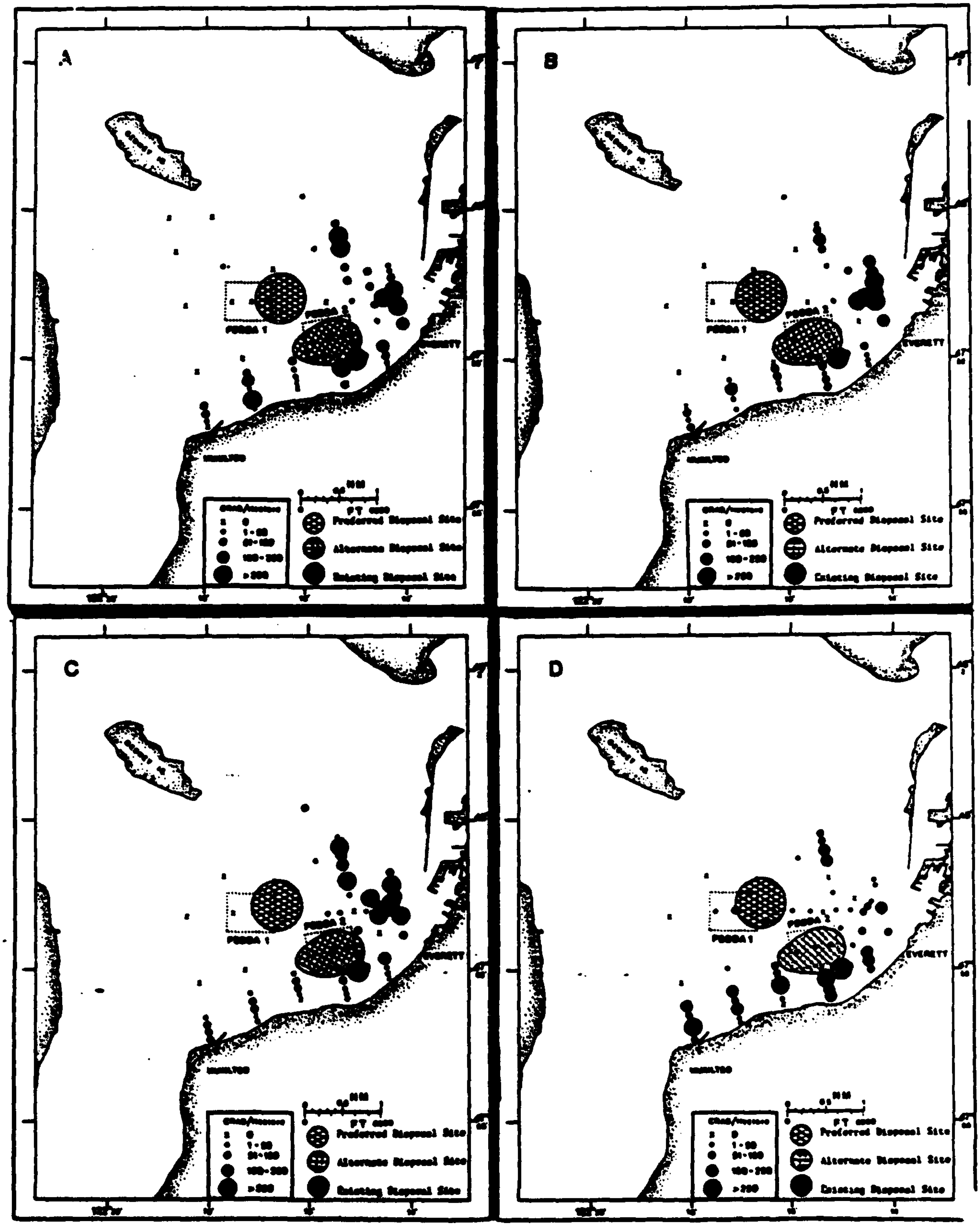


Figure II.8-4 Port Gardner female crab density for: A) February, B) April, C) June, and D) September 1986; beam trawl. (Source: adapted from Dinnel et al., 1986i)

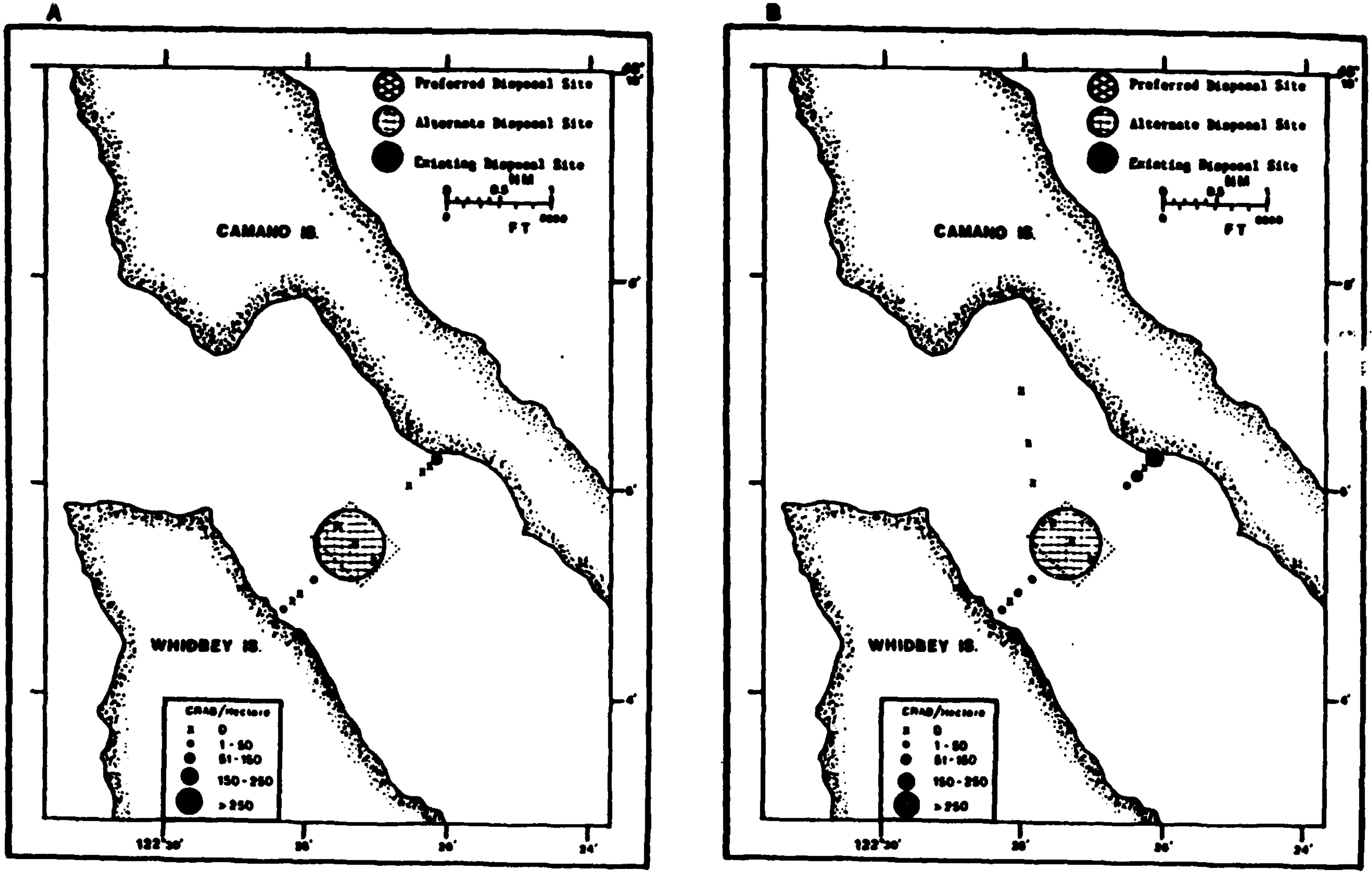


Figure II.8-5 Saratoga Passage total crab density for: A) February, and B) June 1986; beam trawl. (Source: adapted from Dinnel et al., 1986e-h)

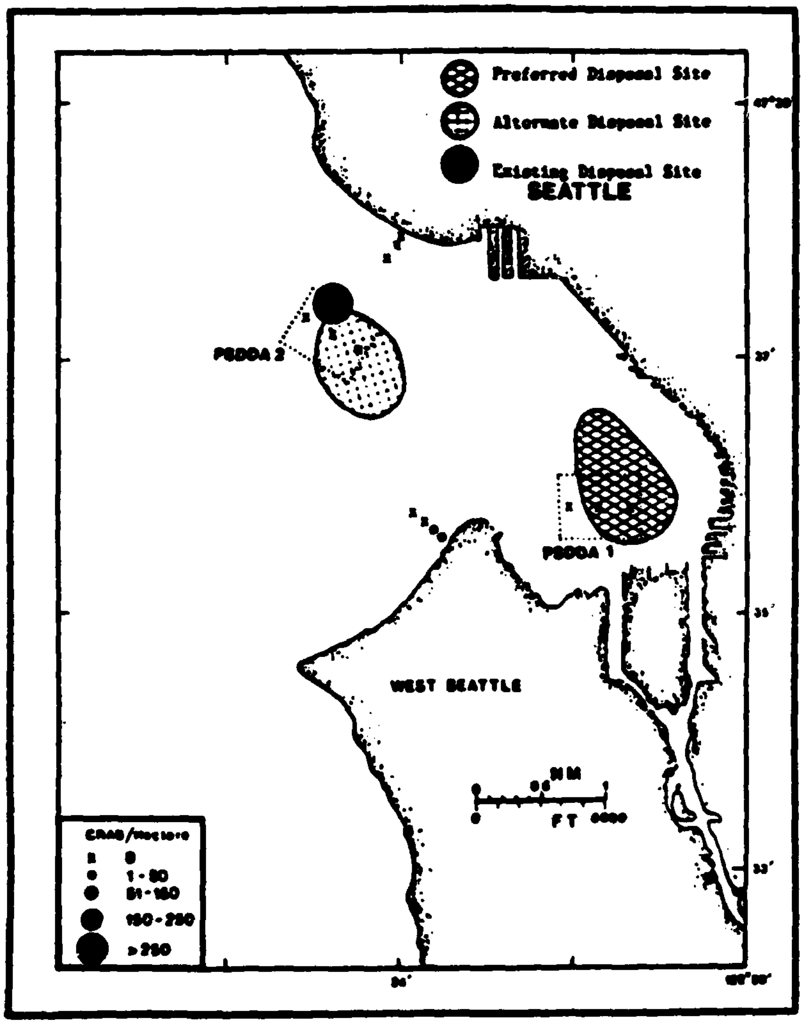


Figure II.8-6 Elliott Bay male crab density for June, 1986; beam trawl. (Source: adapted from Dinnel et al., 1986f)

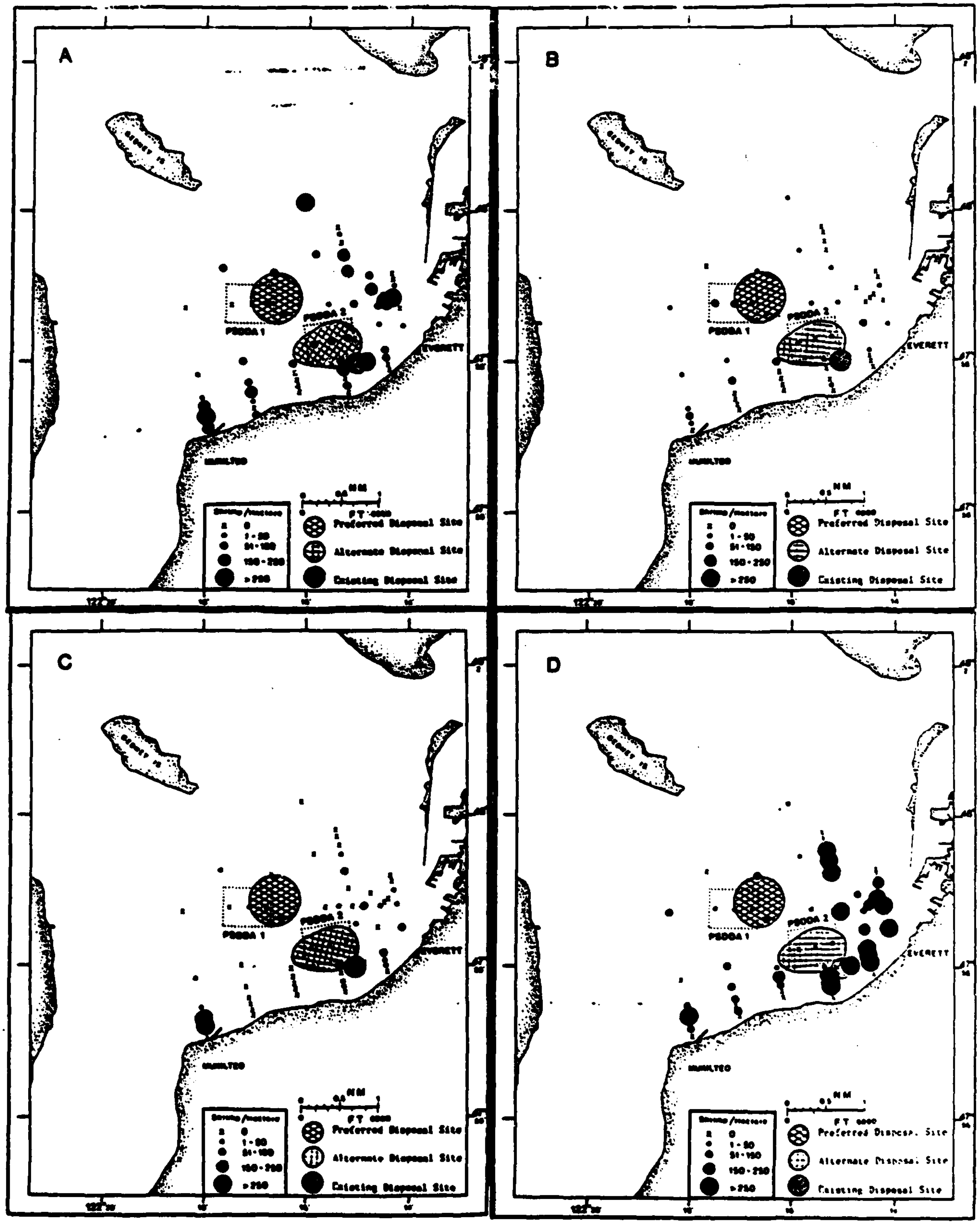


Figure II.8-7 Port Gardner shrimp abundance for: A) February, B) April, C) June, and D) September 1986; beam trawl. (Source: adapted from Dinnel et al., 1986i)

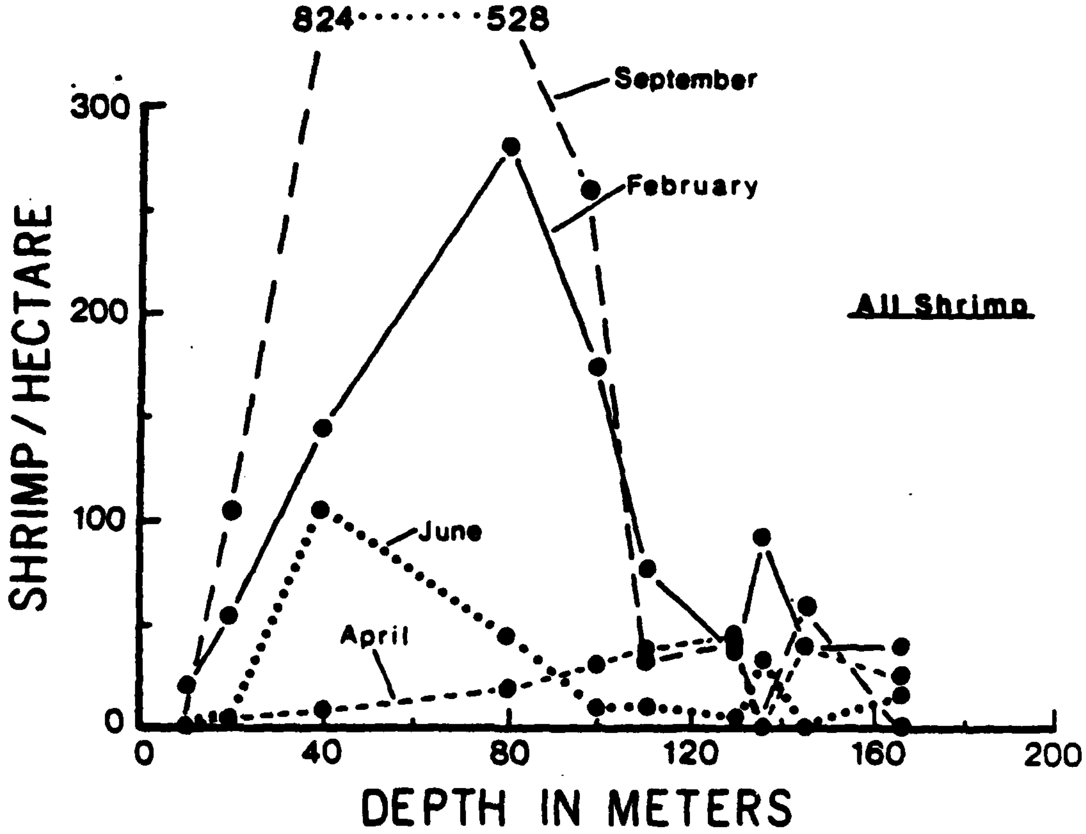


Figure II.8-8 Average commercial shrimp densities by depth and by season in Port Gardner. (Source: adapted from Dinnel et al., 1986i)

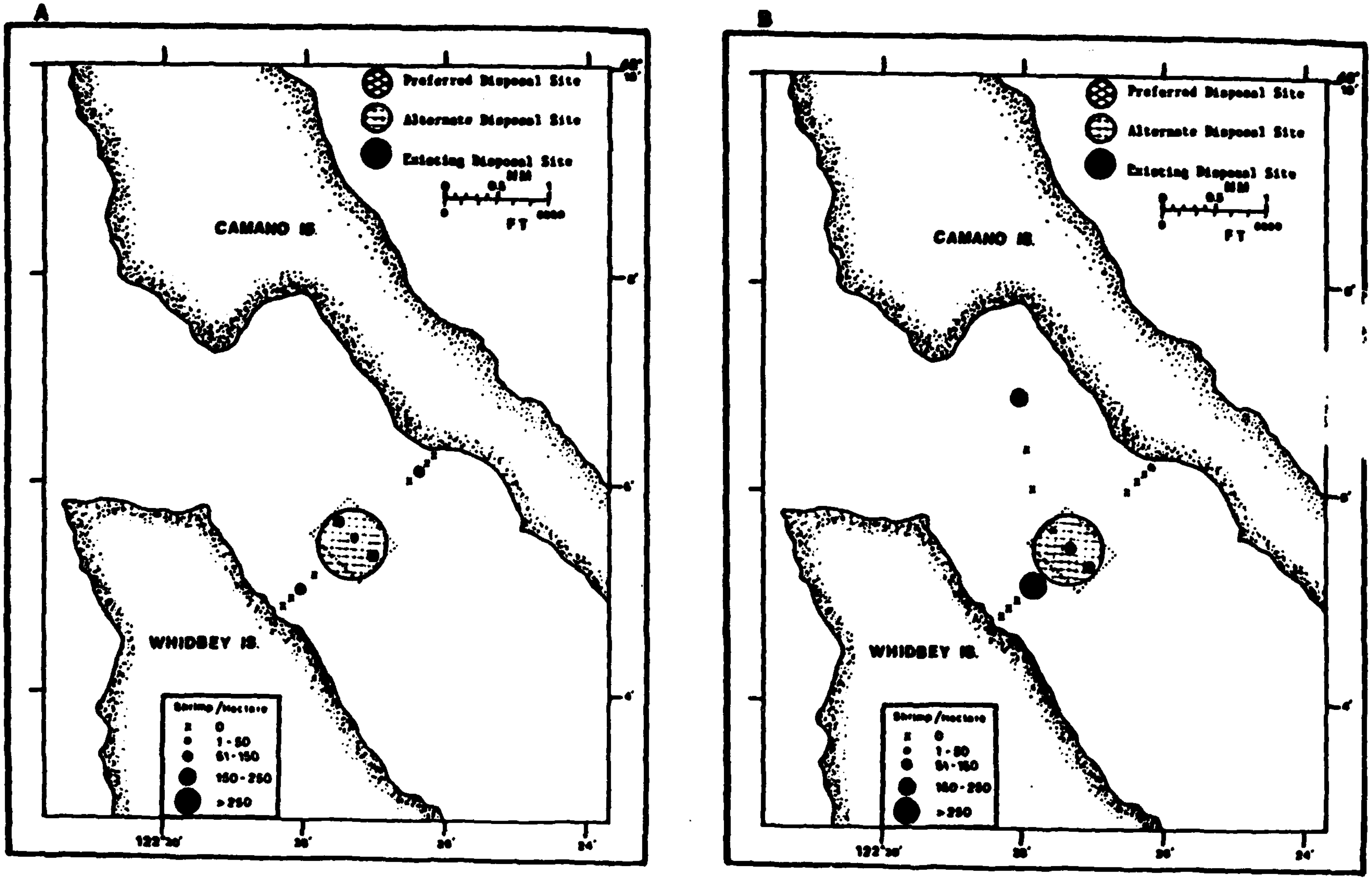


Figure II.8-9 Saratoga Passage shrimp abundance for: A) February, and B) June 1986; beam trawl. (Source: adapted from *Dinnel et al.*, 1986e-h)

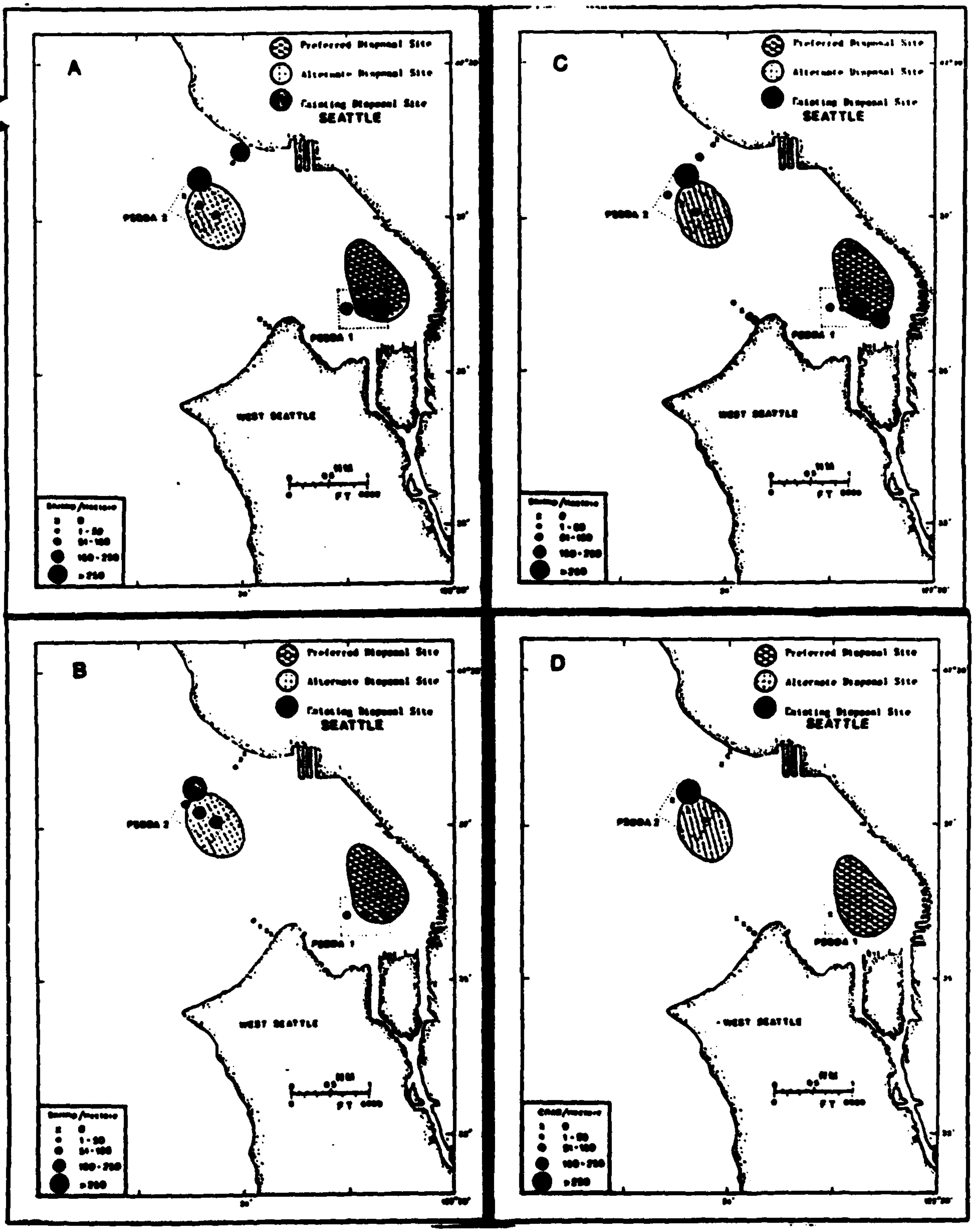


Figure II.8-10 Elliott Bay Seasonal Shrimp Densities; A) February, B) June, and C) September 1986. Crab Densities; D) June 1986. (None found in February and September. (Source: adapted from Dinnel et al., 1986i)

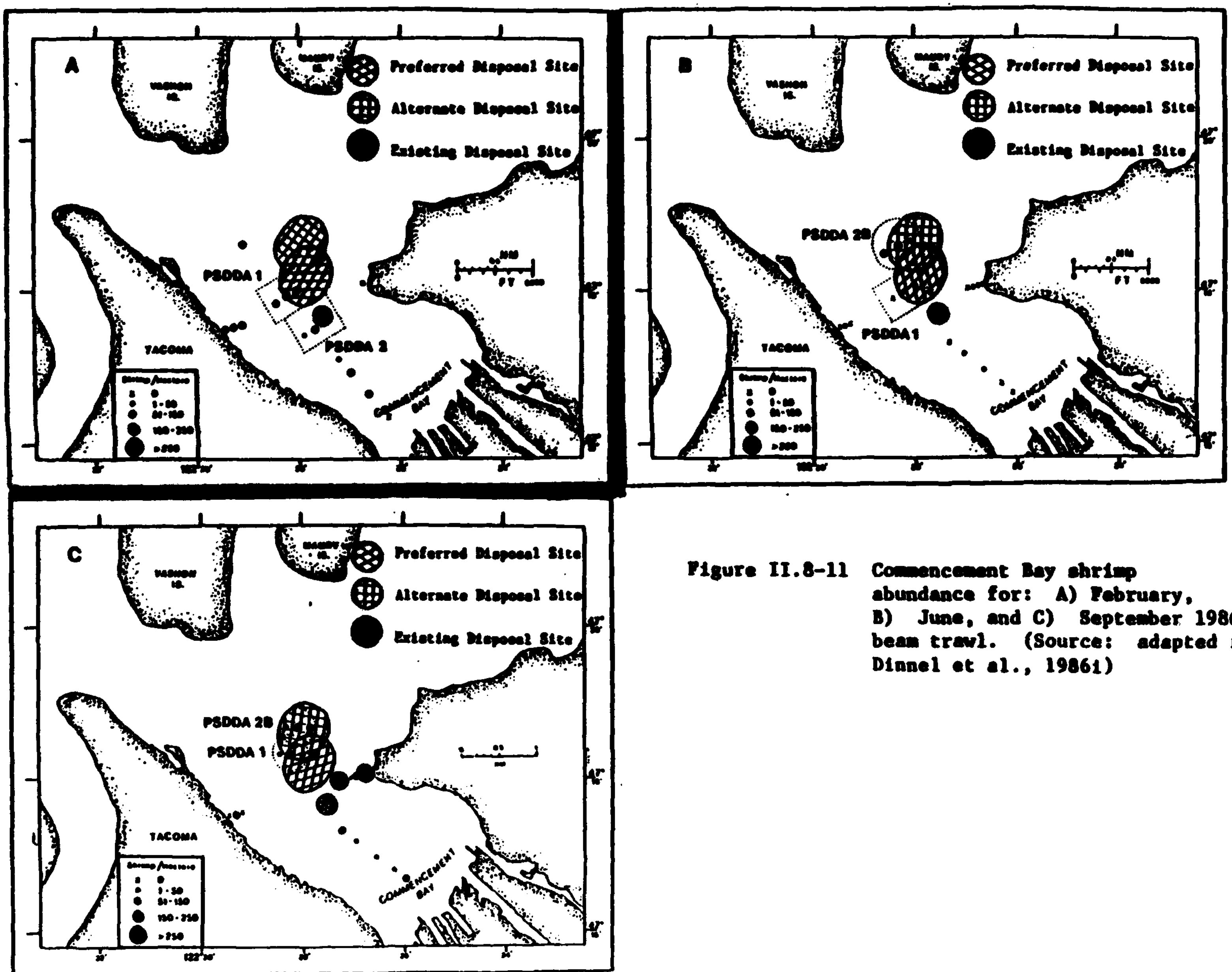


Figure II.8-11 Commencement Bay shrimp abundance for: A) February, B) June, and C) September 1986; beam trawl. (Source: adapted from Dinnel et al., 1986i)

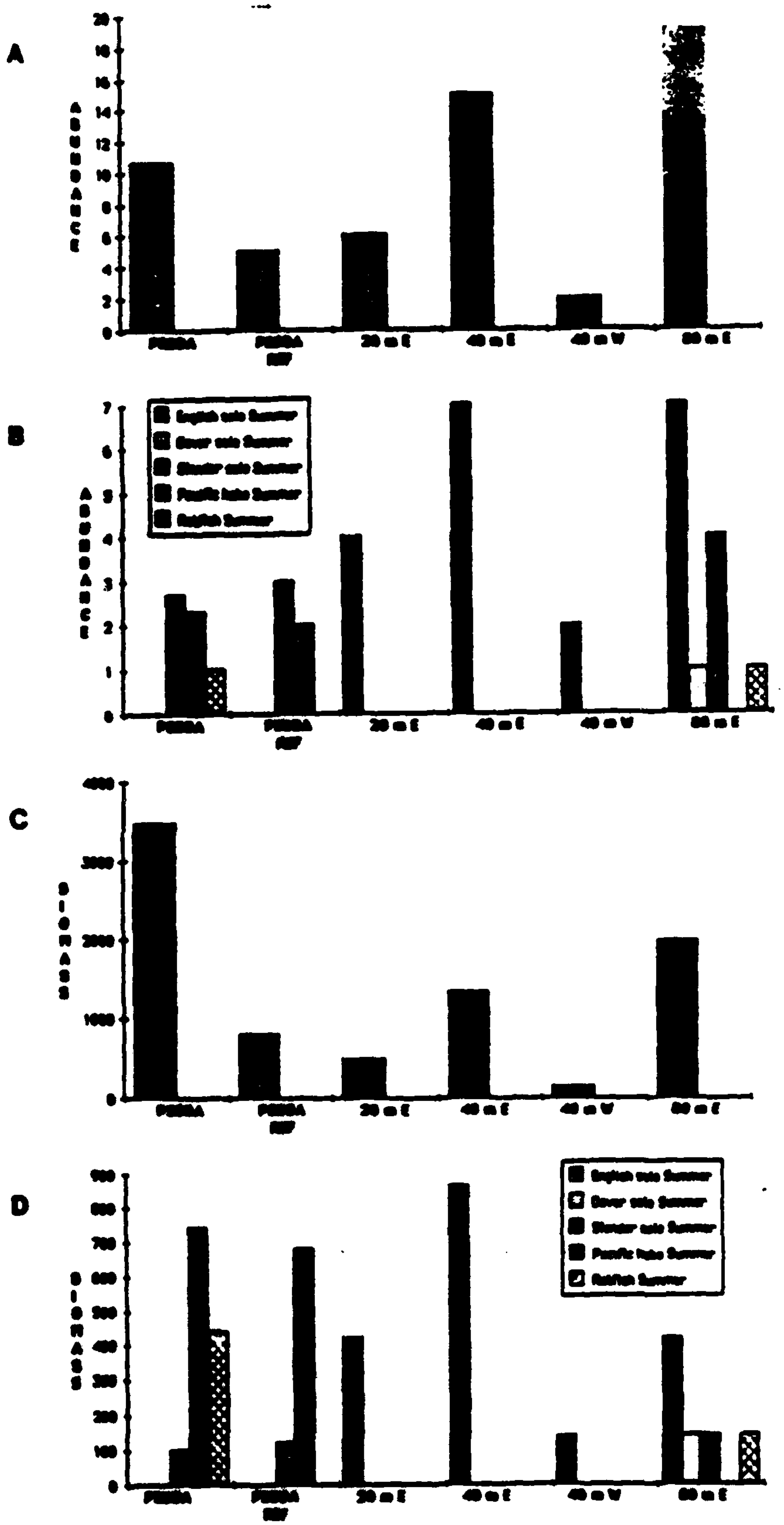


Figure II.8-12 Saratoga Passage, summer caught bottomfish: A) abundance, B) abundance by species, C) biomass (grams), and D) biomass (grams) by species. (Source: Dinnel et al., 1986h)

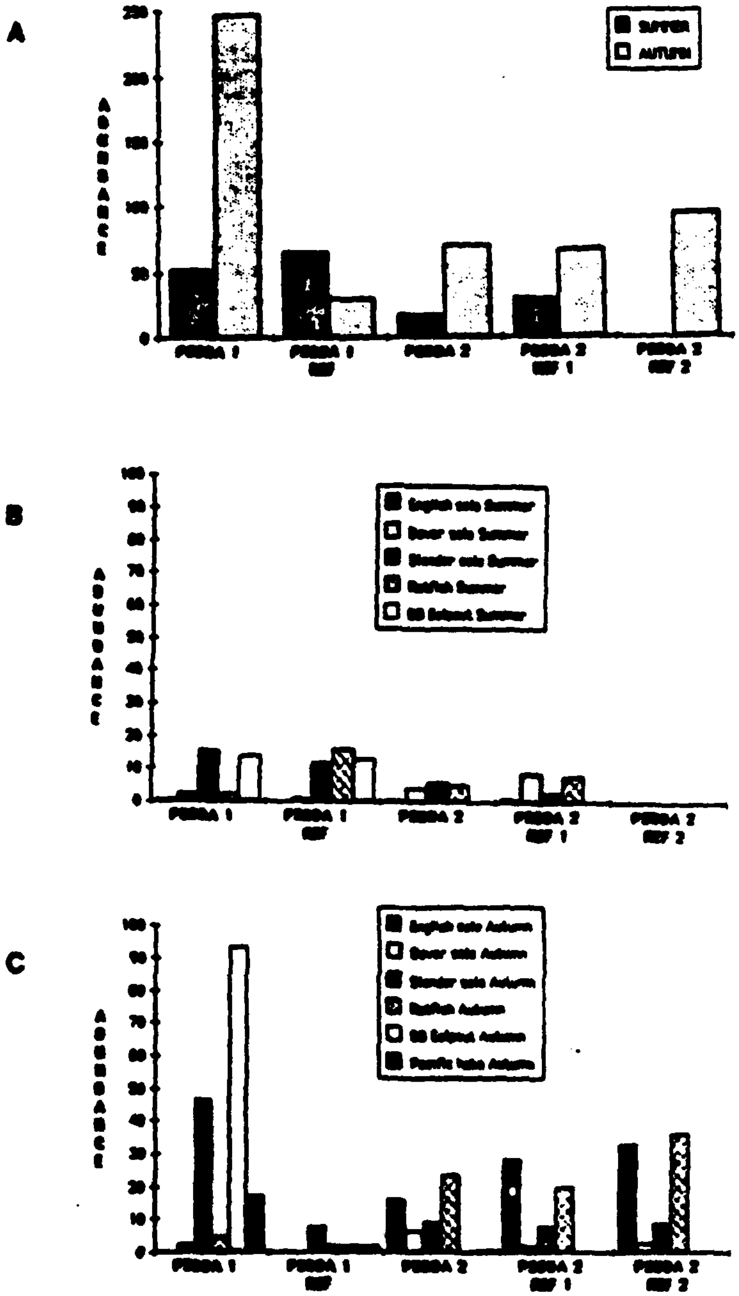


Figure II.8-13 Elliott Bay bottomfish: A) abundance by season, B) abundance by species during summer, and C) abundance by species during autumn. (Source: Dinnel et al., 1986h)

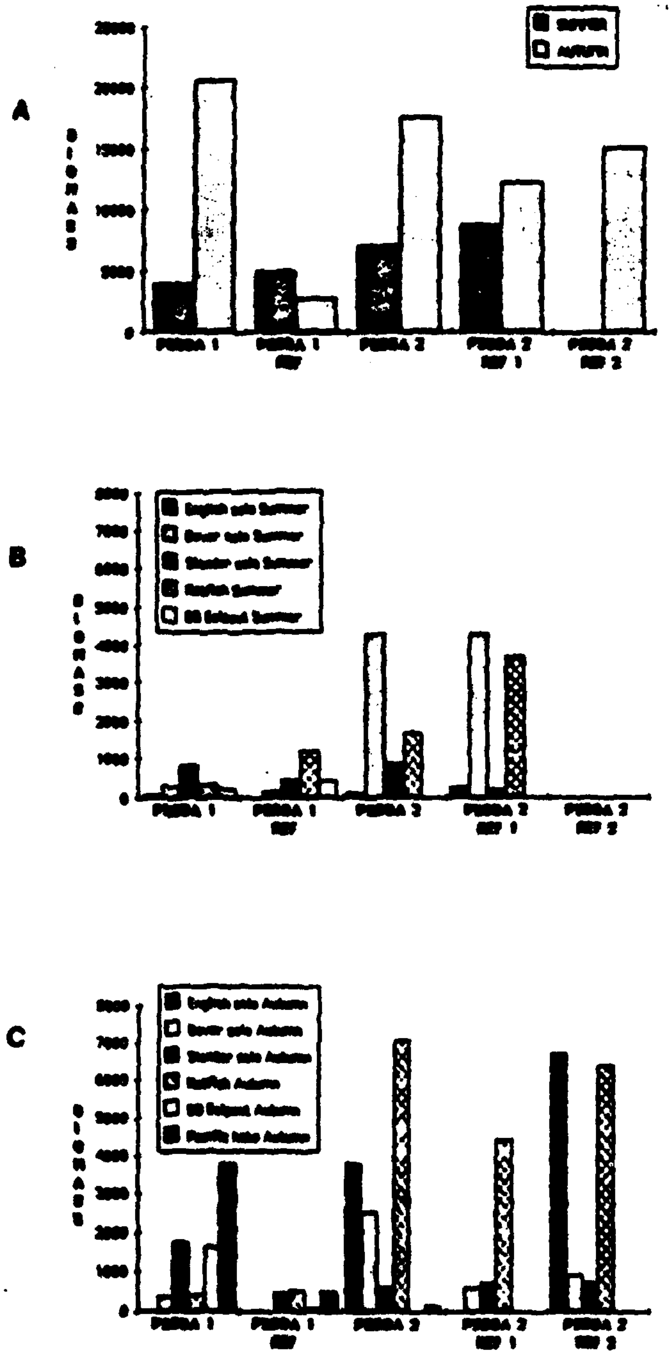


Figure II.8-14 Elliott Bay bottomfish: A) biomass (grams) by season, B) biomass (grams) by species during summer, and C) biomass (grams) by species during autumn. (Source: Dinnel et al., 1986h)

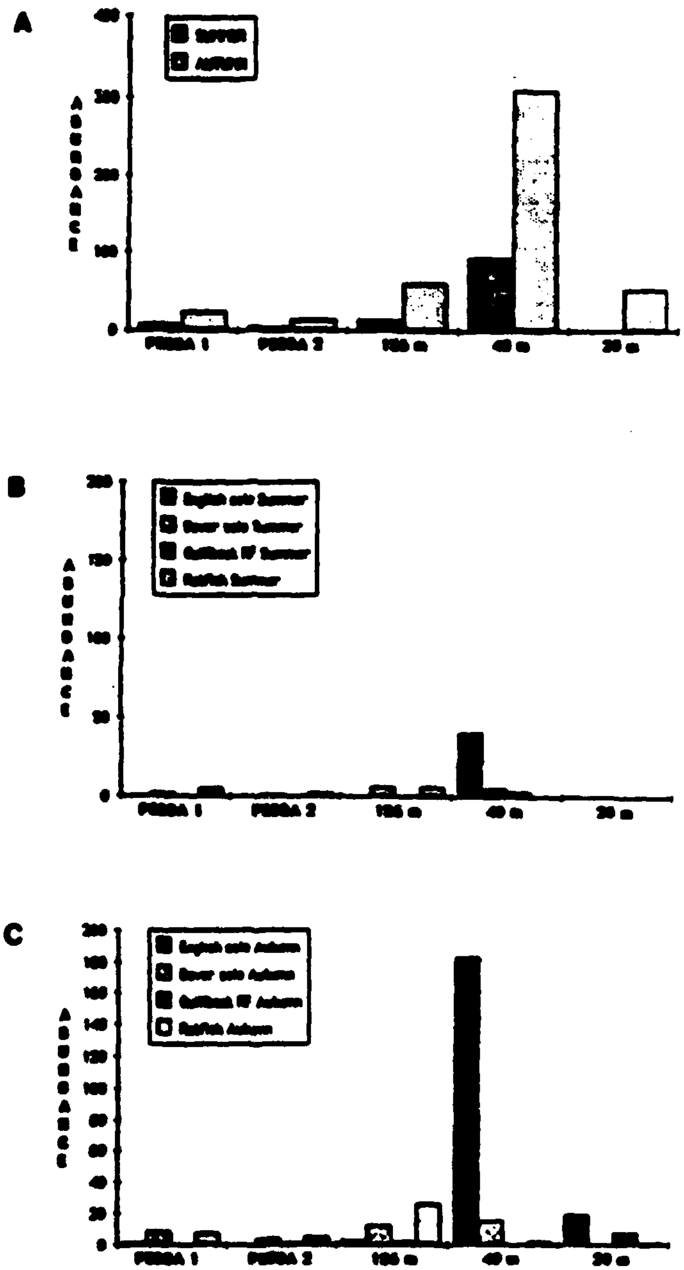


Figure II.8-15 Commencement Bay bottomfish: A) abundance by season, B) abundance by species during summer, and C) abundance by species during autumn. (Source: Dinnel et al., 1986h)

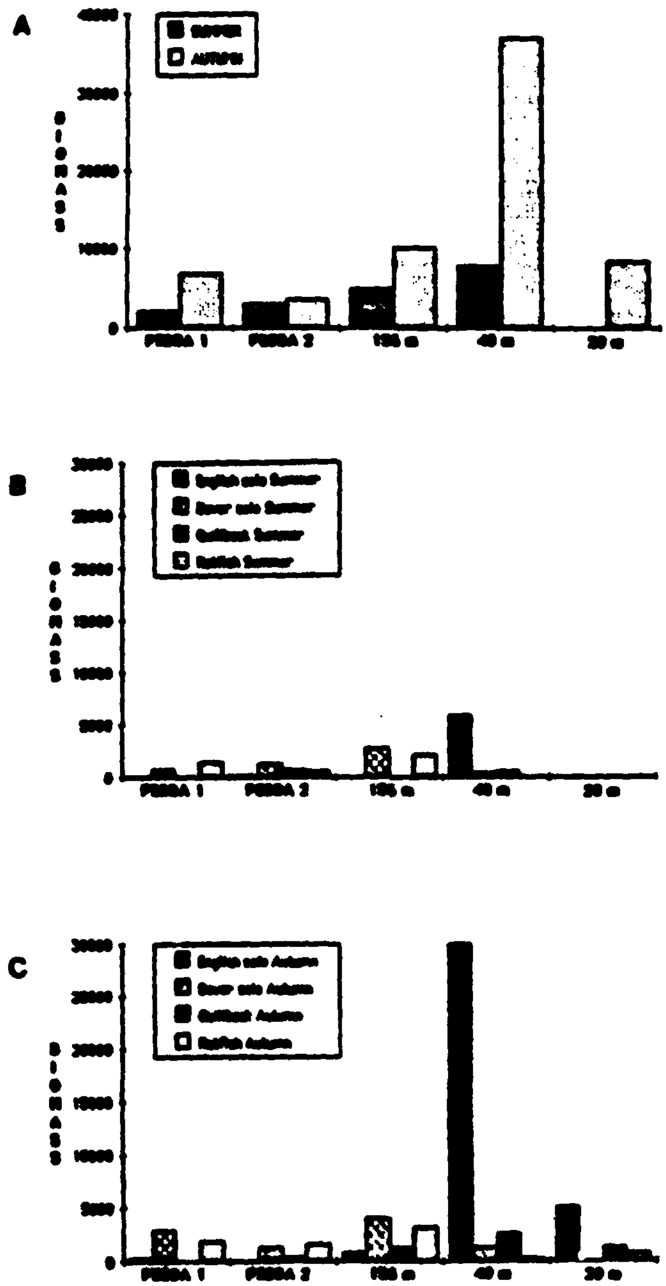


Figure II.8-16 Commencement Bay bottomfish: A) biomass (grams) by season, B) biomass (grams) by species during summer, and C) biomass (grams) by species during autumn. (Source: Dinnel et al., 1986h)

9. BIOLOGICAL RESOURCES: BENTHIC HABITAT/CHARACTERISTICS MAPPED USING THE BENTHIC RESOURCES ANALYSIS TECHNIQUE (BRAT).

9.1 Objective

To characterize the food value of benthic organisms to bottom-feeding fish.

9.2 Background

Coastal engineering projects often cause disturbances of soft (muddy or sandy) bottom habitats in estuarine systems, e.g., dredged material disposal operations. An environmental question that often arises is: Will this project result in unacceptable changes to the habitat involved? Presuming that the potential habitat loss concerns physical disturbance rather than chemical contamination, the resource manager has few tools with which to judge the biological response to the disturbance.

Traditionally, monitoring efforts have relied upon characterizations of the benthic community. Often these field studies produced extensive faunal lists with detailed information on the number of taxa abundance and biomass of the benthic organisms. These data, despite having been obtained through labor intensive field sampling and laboratory analyses, can provide great insight into project impacts; however, they are more costly and require a great amount of time to complete.

The trophic food web linkages between benthic organisms, key fish and shellfish, and ultimately to humans via commercial and recreational fisheries appears to offer resource managers a meaningful way of assigning comparative values to alternative disposal sites. For this reason the DSWG decided not to undertake traditional benthic characterizations, but rather utilize the Benthic Resources Analysis Technique (BRAT) as described below. Because it is not a traditional approach, some additional explanation of the method has been added.

Several years ago the Army Corps of Engineers Waterways Experiment Station developed a set of procedures to estimate the potential trophic value of soft-bottom habitats. These procedures are collectively known as the Benthic Resources Assessment Technique. The BRAT estimates the benthos at a given site that is both vulnerable and available to selected fish species. Different species of bottom-feeding fishes can detect, capture, and ingest only a portion of the available benthos and will consume different prey at different locations and seasons reflecting vulnerable prey. In the BRAT, vulnerability is taken to be a function of the size of the benthic food item, and availability is a function of the depth of the prey's location below the sediment-water interface. Both factors are

estimated from an examination of the diets of target predatory fish, and confirmed by a parallel examination of vulnerable and available prey in the local benthic environment.

Figure II.9-1 depicts the major steps of the BRAT to the beginning of the statistical and numerical analyses. Benthos and fish are collected concurrently in the vicinity of a site where the benthos are segregated according to depth. After separation from the sediments, the vertical distribution of potential food items in the benthos at each station is established by size and weight. Cluster analysis is used to objectively group all stations exhibiting similar size, sorted benthos distributions, and relative biomass contributions. This procedure is accomplished separately for each successive cumulative depth fraction (i.e., 0-2, 0-5, 0-10, and 0-15 centimeters), and allows uniform benthic biomass strata (habitats) to be mapped.

Collected by conventional trawling methods, the fish are measured and separated into size classes. Stomach content samples for each target fish species within each size class are pooled, then treated in a manner identical to the benthic samples. First, the food items are separated into major taxonomic groups (i.e., crustacea, annelida, mollusca, etc.); sieved into standardized size classes and then wet-weighed. Thus, a record is obtained of the size of prey items and their relative proportions utilized by bottom-feeding fish in an area at a given time. Also obtained is a record of the locations of prey utilized in the sediment column. What follows is a comparison of the actual food items eaten and food item, size/depth distribution yielding an estimate of the potential trophic support represented by a specified area of bottom habitat. The final steps involved in determining potential trophic support of a given habitat are illustrated in Figure II.9-2.

Each size class of a given fish species is expected to exhibit a particular prey exploitation pattern, i.e., its diet will be composed predominantly of prey items in a certain size range. This size range may be either narrow or broad. For areas in which there are multiple target fish species and multiple size classes of each species, cluster analysis is used to assign each predator species size class to a prey exploitation pattern. Cluster analysis is used to objectively sort fish size classes into feeding strategy groups based on the uniformity of into size-sorted prey items. Cluster analysis assists in the recognition of patterns in this complex data set. The BRAT produces a list of fish size classes sorted into groups having similar prey exploitation patterns, or feeding strategies.

The second component of prey exploitation that is evaluated is the vertical foraging capability for each fish size class. Qualitative examination of each sample provides evidence of the kinds of prey and their relative abundance. Comparison of this

information with the vertical distribution patterns of these prey in the sediment column (derived from published reports or from direct observations from the vertically partitioned box-core samples) gives an indication of the sediment depth to which a particular fish species or guild of species can forage.

9.3 Methods

During 13 June - 8 July 1986, box-core and otter trawl samples were collected in the vicinity of the four ZSFs: Saratoga Passage; Port Gardner; Elliott Bay; and Commencement Bay. Most of the sampling was done in the Priority 1 and 2 disposal sites, with some additional stations serving as references.

9.3.1 Benthic Sampling and Processing--

A total of 40 benthic samples were taken at the four areas as follows: Saratoga Passage, 4 stations; Port Gardner, 10 stations; Elliott Bay, 14 stations; and Commencement Bay, 12 stations. The cores were collected using a 0.062 square meter Gray O'Hara stainless steel box-corer fitted with an acrylic plastic liner. As soon as the corer was retrieved, the liner containing the undisturbed sample was removed and processed as follows. Beginning at the sediment-water interface the core was divided into vertical sections between the following depths: 0-2; 2-5; 5-10; and 10-15 centimeters. The 0-2 centimeter section was washed into a 0.25 millimeter mesh seive bucket. The remaining vertical sections were individually washed into a 0.5 millimeter mesh sieve bucket. Each sediment sample was sieved by immersing the bucket in a 30 gallon container filled with ambient seawater, and gently shaken and swirled to suspend the larger material and to allow fine sands, silts and clays to pass through the screens. Residual material including benthos was placed in cloth bags, tied, and preserved in 10% seawater-buffered formalin with a 0.2% Rose Bengal solution. All four vertical sections were then taken to the laboratory for analysis.

Samples were sorted into major taxa for each of the four depth fractions from each box core and were then individually separated into discrete size class intervals by a wet sieving procedure described by Carr and Adams (1973) and Sheridan (1979). The nested, graded 3-inch standard sieves used in the benthic analysis were: 6.35; 3.35; 2.0; 1.0; and 0.5 millimeters. A 0.25 millimeter mesh sieve was added for processing the 0-2 centimeter depth fraction. Each sample was carefully washed through the nested sieves using a gentle water rinse, taking care not to damage soft-bodied benthic organisms. Each sieved sample was then filtered through a 45 micrometer millipore filter and then quantitatively transferred to weighing

bottles. Taxa sorted from the 0.25 millimeter sieved sample for the 0-2 centimeter depth fraction were weighed directly after filtering. Wet-weight biomass was initially recorded to 0.01 gram and the sample returned to a vial containing 70% alcohol. In a few cases, when the available biomass was small, a higher level of accuracy was required (0.1 milligram).

For the 0-2 centimeter vertical depth fraction all individuals of each major taxon were enumerated. Approximately 150 individuals of each major taxon were divided into five subsamples each having 30 individuals. Each subsample was weighed to the nearest 0.001 milligram. Average individual weight, standard deviation, and the coefficient of variation for all five subsamples were then calculated. The average individual weight was then used to estimate the total weight of that taxon in the sample obtained by multiplying the mean by the total number of individuals enumerated. Biomass data were converted to grams per square meter (wet weight) and incorporated into the evaluation.

9.3.2 Fish Sampling and Processing--

Fish collections were conducted concurrently in the vicinity of the benthic sites using a 25-foot otter trawl. The trawls were distributed as follows: Saratoga Passage, 4 trawls; Port Gardner, 7 trawls; Elliott Bay, 8 trawls; and Commencement Bay, 8 trawls (see Clarke, 1986 for trawl locations).

The trawls were of relatively short duration (approximately five minutes) to minimize deterioration and regurgitation of the gut contents by the fish. Target bottom-feeding fish species representative of demersal fish utilizing each site included five species of sole: English sole (Parophrys vetulus); Dover sole (Microstomus pacificus); slender sole (Lyopsetta exilis); rex sole (Glyptocephalus zachirus); and flathead sole (Hippoglossoides elassodon). Fish collected along each transect were processed as follows. Demersal bottom-feeding fish were separated from pelagic fish which did not feed on the benthos. The catch was then sorted by species and divided into Standard Length size classes: 5-9.9; 10-14.9; 15-19.9; 20-24.9; 25-29.9; and greater than 30 centimeters. Individuals of the same species and size class captured at the same location were processed for analysis according to the procedures described by Borgeson (1963).

Stomach contents representing individual species size class samples were picked and sorted to major taxonomic categories (e.g., Mollusca, Annelida, Crustacea, etc.). Sorted-by-taxon samples were individually seperated into discrete size class categories by a wet-sieving procedure described by Carr and Adams (1973) and Sheridan (1979). Wet-sieving was accomplished using a 3-inch diameter set of nested sieves from top to bottom in the following sequence: 6.35; 3.35; 2.0; 1.0; 0.5; 0.25; and

0.063 millimeters. In a manner similar to the treatment of the benthic samples, the stomach contents from each sieve were vacuum-filtered onto pre-weighed 0.45 micron millipore filters. Wet-weights were recorded to the nearest 0.01 gram and the sample returned to a container with 70% alcohol. Weights were tabulated by site, predator species, major taxon, and sieve size category.

9.4 Data Analysis

Examination of the benthic data indicated that large patches of biomass, particularly in the deeper sediment fractions, were contributed by Holothuroids and, rarely, Echinoids. These taxa, as evidenced by the fish stomach contents, were not utilzed as prey items by any of the target fish. Because their large biomass would otherwise mask the importance of contributions made by the remaining benthic taxa, Holothuroid and Echinoid biomass data were deleted from the benthic data set.

For each cumulative sediment depth fraction, size-partitioned biomass data were subjected to cluster analysis to assign benthic samples to clusters on the basis of their similarities in benthos-size distribution and relative biomass contribution. Patterns of high or low benthic biomass and size distribution were discernible when these data were superimposed on the grid of the sampling stations.

Each benthic biomass cluster was then evaluated in terms of the potential trophic support afforded to each predator group. This step involves summation of the vulnerable prey biomass from the sediment surface down to the lowest zone of prey availability. Thus each benthic cluster had a prey biomass for each predator group (grams per square meter). These values represent the potential prey biomass for target predator species, and allow comparative estimates to be made of the trophic support afforded by various sites within each ZSF.

9.5 Results

In the BRAT analysis benthic samples were sorted into major taxonomic categories. Annelids and molluscs comprised the major components of the benthos at almost all study areas. In terms of biomass, annelids generally dominate the benthos in Commencement Bay, at the Elliott Bay Priority 1 site, and at the Port Gardner Priority 1 site. Visual inspection of the benthic samples indicated that polychaetes of the families Ophiliidae, Spionidae, and Maldanidae were important members of the infauna. Molluscs, primarily bivalves of the genera Axinopsida and Macoma, were found at all study areas, but were dominant at both the Port Gardner and Elliott Bay Priority 2 sites. Annelids

appear to be important members of the benthos in the Saratoga Passage ZSF. Crustaceans, largely mysids and mud shrimp, contributed generally less than ten percent to the mean biomass at any ZSF.

Figure II.9-3 shows the vertical distribution of biomass at stations within the Priority 1 and 2 disposal sites in the four study areas. These curves show the mean values within the disposal sites. It will be seen later that the fish collected appeared to be foraging in two depth ranges: 0-5 and 0-10 centimeters. Therefore the discussion of biomass will be restricted to the 0-10 centimeter range. Throughout this range the biomass in Saratoga Passage lies substantially below the values in the other areas of Puget Sound. Within Port Gardner the biomass in the Priority 1 disposal site equals approximately half of that found in the Priority 2 site. In Elliott Bay the biomass is approximately equal in the Priority 1 and 2 disposal sites. In Commencement Bay the biomass is approximately equal in the 0-5 centimeter depth range, whereas between 5-10 centimeters the Priority 2 site has nearly three times greater biomass than the Priority 1 site.

Benthic biomass data were clustered using size-partitioned and total biomass as attributes for each station. Thus stations from different study areas could, based on their similarity in biomass distribution, occur in the same cluster. Importantly, it should be noted that clusters are formed independent of taxonomic composition. In this data set, there appeared to be no remarkable differences among most stations in their size-partitioned biomass distribution. As a result, although biomass data were transformed prior to clustering, total biomass at a station was an important determinant of cluster composition.

A total of 22 species-size class samples were used in the analysis meeting a criterion sample size of at least three stomachs containing identifiable material (Table II.9-1). Among these species-size classes, a total sample of 244 stomachs were examined. The sample size was unequal among species and study areas, generally reflecting the composition of the catch. For example, slender sole was the most abundant species captured, although insufficient numbers were taken at Commencement Bay to comprise a sample. In contrast, Dover sole ranked second in abundance, but were not present in sufficient numbers to form a species-size class at Saratoga Passage. English sole were present at Commencement Bay and Port Gardner, but were not captured elsewhere. Flathead sole and Rex sole were taken in small numbers at Elliott Bay, and Commencement Bay and Elliott Bay respectively. The largest catch (121 fish) was taken at Elliott Bay, whereas both Commencement Bay and Saratoga Passage were represented by substantially smaller catches. Dover sole and English sole were represented in the catch by relatively larger size classes (greater than 20 centimeters). Descriptions of the five species of sole are given below.

Slender Sole (Lyopsetta exilis) - The moderate sized mouth gape and large eyes are morphological features of this species that fit a feeding strategy for utilization of active, mobile prey. The diets of slender sole in the 5-9.9 and 10-14.9 centimeter size classes consisted largely of mysids, which were probably taken epibenthically or in the water column just above the bottom. Some indication of predation on infauna was evidenced by small percentages of nematodes, amphipods, and polychaetes. Slender sole in the 15-19.9 centimeter class ate somewhat more diversified prey items. Mysids and decapods comprised most of the diets, but also present were copepods, bivalves, polychaetes, amphipods, and nematodes.

Dover Sole (Microstomus pacificus) - In contrast with the slender sole, Dover sole display the classic morphological features of an infaunal-feeding flatfish. The terminally placed mouth has a small gape and is asymmetrical, facilitating downward orientation during feeding. Most Dover sole size class samples fed largely on annelids. Bivalves were also important, particularly for larger size classes (25-29.9 and 30-34.9 centimeters) at the Port Gardner Priority 2 disposal site. Dover sole taken from the Elliott Bay Priority 2 disposal site exhibited comparatively high diversity of stomach contents, including mysids, amphipods, cumaceans, isopods, and ostracods in appreciable amounts.

English Sole (Parophrys vetulus) - This species also shows the morphological features characteristic of an infaunal-feeder. Samples of English sole were obtained only at Commencement Bay and Port Gardner. At Commencement Bay, fish in the 20-24.9 centimeter size class preyed mainly on polychaetes, with bivalves forming a smaller portion of the diet. The same size class at the Port Gardner Priority 1 disposal site had a similar diet, with the addition of urochordates. In contrast, two samples at the Port Gardner Priority 2 disposal site fed primarily on bivalves.

Flathead Sole (Hippoglossoides elassodon) - Flathead sole, having a relatively large mouth gape, displayed a feeding strategy similar to that of the slender sole. In the present study samples of flathead sole were obtained only at Elliott Bay in the vicinity of the Priority 1 disposal site. The smallest size class (10-14.9 centimeters) had a high proportion of nematodes in their stomachs, with mysids and amphipods being of secondary importance. Fish in the 15-19.9 centimeter size class had stomach contents which varied greatly among samples, but were dominated by decapods, fish, and/or bivalves.

Rex Sole (Glyptocephalus zachirus) - The rex sole is another small-mouthed flatfish. Only two rex sole samples were obtained. One rex sole taken at Commencement Bay contained largely unidentifiable digested material. A fish (5-10 centimeters) from the Elliott Bay Priority 1 disposal site had eaten decapods, copepods, and amphipods.

The results of the cluster analysis and graphical treatment of the food habits biomass data were used to classify species and size classes into prey size feeding strategy groups as described in Table II.9-2. Table II.9-3 lists the fish species and size classes that were assigned to each group. Note that in some instances the same size class of the same fish species exhibits a different feeding strategy at different locations. For example, English sole representing the 25-29.9 centimeter size class from the Port Gardner Priority 2 disposal site and reference site fell into groups IIIA and IIB, respectively. The differences noted are probably attributable to subtle patchiness in the distributions of the benthos.

Observed differences in prey size exploitation patterns by the same species and size class captured from two locations lead to questions regarding feeding efficiency. Data on the weight of each fish stomach contents sample and the number of stomachs that comprised each pooled sample were used to calculate the mean weight of food in each sample (Table II.9-4). These calculations indicated no substantial differences in feeding efficiencies among the study areas.

For each fish group a determination was made of the portion of the total benthic biomass that was both vulnerable and available to predation. Those portions of the total biomass determined to be either too small or too large to fit a predator group's feeding strategy (not vulnerable), or beyond that predator group's foraging depth (not available) were deleted from the appropriate cluster's total biomass.

Comparison of the taxonomic composition of the stomach contents of fish size class samples in each predator feeding strategy group revealed that, in several cases, a group consists partially or mainly of epibenthic rather than infaunal feeders. Groups which contain no evidence of infaunal feeding (i.e., Groups II, IID, and IIIB) are of little importance in assigning a value to the benthos as trophic support. Therefore, these groups received no further consideration in the analysis. Groups IIA, IIB, IIC, and IIIA, however, do contain fish samples that have utilized infaunal prey items and are treated below.

First, an estimate was made of the size range of prey being exploitated by a given predator group. Table II.9-2 lists the benthic prey sizes observed contributing at least ten percent to the overall diet for each of the various fish groups. Second, a determination was made of the foraging depth of the selected fish groups. This is the most subjective step in the overall analysis, and requires extensive investigation of the data sets. For example, if polychaetes are the major prey taxon of a particular predator group, examination of the vertical distribution of vulnerable polychaete biomass in the sediments at stations adjacent to the trawl transects from which the fish samples were captured can provide insight into the probable foraging depth of those fishes. If the major concentration of vulnerable polychaete biomass lies between two and five

centimeters, then a conclusion can be reached that the fishes are exploiting the 0-5 centimeter sediment depth fraction. This approach, however, must consider the behavior of the specific prey items. Many species of polychaetes which build tubes deep into the sediment are surface deposit-feeders. Although fish are able to crop the exposed portions of the annelids at the sediment surface, the biomass for these polychaetes may actually be found quite deep in the box-corer samples. During sampling these and other annelids might be expected to retract downward into their tubes. Based on considerations such as these, an estimated foraging depth for each predator group was reached.

The results of the benthic resource computations for each ZSF are presented in Figures II.9-4 through II.9-7. For example, for Group IIA and IIC predators, a five centimeter foraging depth was used. From the total available biomass in the 0-5 centimeter sediment depth zone, that portion of the available biomass outside of the vulnerable range of prey size was removed. This operation was repeated for each 0-5 centimeter benthic stratum at each station. The biomass remaining was then a measure of the potential benthic biomass that could be potentially exploited as food by Group IIA fish at stations in that respective depth range. For Group IIB and IIIA fish a zero to ten centimeter foraging depth was used.

An initial statement of the limits of the data is required. Because the data represent a single summer sampling effort, extrapolation of the results to a complete seasonal cycle is impossible. However, the data do describe conditions during a period when benthos were actively being exploited by fish populations. A second limitation of the data is that sampling effort was unequal among study areas such that not all species were sampled at each site. This reflects variation in the habitat preferences of the selected species. Sufficient data were obtained to reach conclusions regarding two key target species: Dover sole and English sole. Populations of slender sole, flathead sole, and rex sole were present at several study areas during sampling, although they were preying heavily on non-infaunal organisms. Mysids in particular appeared to be abundant at both Saratoga Passage and Elliott Bay, as evidenced by the proportions of this taxon in the fish food habits samples. During those times when mysids and other epibenthic prey become less available, these predator species probably become more dependent upon infaunal prey.

Despite the patchiness in the biomass available to the fish, some trends are apparent in the contoured data. Because of low potential biomass, the amount that is available to all the predators in Saratoga Passage is also quite low compared with values in the three embayments. It may be that the biomass in Saratoga Passage is typical of typical mid-channel areas of Puget Sound located away from the more productive embayments.

In Port Gardner the biomass available to the four groups of predators decreases from east to west (Fig. II.9-5). In Elliott Bay there is a decrease with increased distance offshore from the vicinity of Four Mile Rock (Fig. II.9-6). In inner Elliott Bay several anomalous values are superimposed on the trends. For Groups IIA, IIB, and IIC the biomass decreases toward the northwest, whereas for Group IIIA, the decrease occurs toward the northeast. In Commencement Bay the distribution is quite patchy and it is difficult to determine regional trends (Fig. II.9-7).

TABLE II.9-1 DISTRIBUTION OF FISH STOMACH CONTENT SAMPLES AMONG FOUR ZSFS. FISH LENGTH EQUALS STANDARD LENGTH.

Fish Species	Zone of Siting Feasibility (ZSF)								Total
	Saratoga Passage		Port Gardner		Elliott Bay		Commencement Bay		
	Length (cm)	Sample (#)	Length (cm)	Sample (#)	Length (cm)	Sample (#)	Length (cm)	Sample (#)	
Dover Sole			15-20	3	20-25	9	25-30	3	70
			20-25	13	25-30	7	30-35	9	
			25-30	13	30-35	10			
			30-35	3					
Slender Sole	10-15	7	15-20	4	5-10	5			97
	15-20	12			10-15	23			
					15-20	46			
English Sole			20-25	28			20-25	8	53
			25-30	17					
Flathead Sole					10-15	5			18
					15-20	13			
Rex Sole					5-10		10-15	3	6
TOTAL		19		81		121		23	244

TABLE II.9-2 DESCRIPTION OF PREY SIZE FEEDING STRATEGY GROUPS.

Group I - Fish feeding on prey less than or equal to 1.0 mm or smaller with a modal prey size of approximately 0.25 millimeter. No representatives of this group were found in this data set.

Group II - Fish that exploit a range of prey sizes and that are not clearly small prey or large prey exploiters. Group II contains four subgroups:

Group IIA - Fish that exploit prey between 0.25 and 2.0 millimeters. A prey size mode of 0.5 millimeter was indicated for benthic prey items.

Group IIB - Fish that exploit prey between 0.5 and 3.35 millimeters. A prey size mode of 2.0 millimeters was indicated.

Group IIC - Fish that exploit prey between 0.5 and 3.35 millimeters. A prey size mode of 3.35 millimeters was indicated.

Group IID - Fish that exploit prey in the 3.35 millimeter size category.

Group III - Fish that do not exploit small-sized prey. Exploitation is predominantly among prey that are greater than 3.35 millimeters. Group III contains two subgroups:

Group IIIA - Fish that exploit prey in the intermediate size range (0.5-2.0 millimeters), but the prey size mode is 6.35 millimeters.

Group IIIB - Fish that exploit only prey in the 6.35 millimeter size category.

TABLE II.9-3 COMPOSITION OF PREY SIZE FEEDING STRATEGY GROUPS.

Fish Group	Species	Size Class (centimeters)	Number of Fish	Site
II	Flathead Sole	10-15	5	Elliott Bay
IIA	Rex Sole	5-10	3	Elliott Bay
	Slender Sole	5-10	5	Elliott Bay
	Slender Sole	10-15	10	Elliott Bay
	Slender Sole	15-20	19	Elliott Bay
	Dover Sole	15-20	3	Port Gardner
	Dover Sole	20-25	5	Port Gardner
	Dover Sole	20-25	4	Elliott Bay
IIB	Slender Sole	10-15	7	Saratoga Passage
	Slender Sole	15-20	12	Saratoga Passage
	Slender Sole	15-20	4	Port Gardner
	Dover Sole	25-30	3	Port Gardner
	Dover Sole	25-30	3	Port Gardner
	Dover Sole	25-30	7	Elliott Bay
	Dover Sole	30-35	3	Commencement Bay
	Dover Sole	30-35	6	Commencement Bay
	English Sole	20-25	8	Commencement Bay
	English Sole	20-25	8	Port Gardner
	English Sole	25-30	3	Port Gardner
IIC	Slender Sole	15-20	6	Elliott Bay
	Dover Sole	20-25	5	Elliott Bay
	Dover Sole	20-25	8	Port Gardner
	Dover Sole	25-30	7	Port Gardner
	Dover Sole	30-35	3	Port Gardner
	English Sole	20-25	20	Port Gardner
IID	Rex Sole	10-15	3	Commencement Bay
IIIA	Flathead Sole	15-20	6	Elliott Bay
	Slender Sole	10-15	7	Elliott Bay
	Slender Sole	10-15	3	Elliott Bay
	Slender Sole	15-20	10	Elliott Bay
	Slender Sole	15-20	11	Elliott Bay
	Dover Sole	25-30	3	Commencement Bay
	Dover Sole	30-35	10	Elliott Bay
	English Sole	25-30	14	Port Gardner
IIIB	Flathead Sole	15-20	3	Elliott Bay
	Flathead Sole	15-20	4	Elliott Bay
	Slender Sole	10-15	3	Elliott Bay

TABLE II.9-4 FEEDING EFFICIENCY OF FISH SAMPLED AT FOUR ZSFS AS INDICATED BY MEAN WEIGHT OF FOOD ITEMS (INCLUDING BENTHOS AND NEKTON) PER STOMACH.

Species	Fish Length (centimeters)	Mean Weight of Food Per Fish Stomach (grams) and sample size (#) Saratoga Passage	Port Gardner	Elliott Bay	Commencement Bay
Slender Sole	5-10			0.094 (5)	
	10-15	0.112 (7)	0.280 (4)	0.102 (23)	
	15-20	0.120 (12)		0.209 (46)	
Dover Sole	15-20		0.209 (3)		
	20-25		0.442 (13)	0.661 (9)	
	25-30		0.653 (13)	0.523 (7)	0.413 (3)
	30-35		0.824 (3)	2.859 (10)	0.788 (9)
English Sole	20-25		0.731 (28)		0.771 (6)
	25-30		1.505 (17)		
Flathead Sole	10-15			0.094 (5)	
	15-20			0.512 (13)	
Rex Sole	5-10				0.535 (3)
	10-15			0.067 (3)	

Table II.9-6 STATISTICAL ANALYSIS OF POTENTIAL HABITAT FOOD VALUE. MEAN AND STANDARD DEVIATIONS HAVE UNITS OF BIOMASS IN GRAMS PER SQUARE METER.

Fish Feeding Group	Study area	Priority 1 Mean	Priority 1 Standard deviaton	Priority 1 Sample size	Priority 1 Coefficient of variation	Priority 2 Mean	Priority 2 Standard deviation	Priority 2 Sample size	Priority 2 Coefficient of variation
IIA	Saratoga Passage					2.6	0	4	0
	Port Gardner	12.3	2.4	4	.20	15.2	0	3	0
	Elliott Bay	12.1	4.9	6	.40	13.5	2.6	5	.19
	Commencement Bay	13.2	2.9	4	.22	12.6	2.4	4	.19
IIC	Saratoga Passage					4.4	0	4	0
	Port Gardner	17.8	3.8	4	.21	28.7	0	3	0
	Elliott Bay	16.7	6.9	6	.41	22.7	6.2	5	.27
	Commencement Bay	19.8	4.1	4	.21	19.6	6.2	4	.32
IIB	Saratoga Passage					4.9	0	4	0
	Port Gardner	19.6	6.5	4	.33	28.3	1.6	3	.06
	Elliott Bay	21.2	9.6	6	.45	24.0	7.7	5	.32
	Commencement Bay	25.8	6.8	4	.26	25.1	6.5	4	.26
IIIA	Saratoga Passage					7.2	0	4	0
	Port Gardner	13.1	11.0	4	.84	43.6	25.0	3	.57
	Elliott Bay	21.0	26.9	6	1.28	17.1	11.0	5	.64
	Commencement Bay	24.3	9.9	4	.41	35.1	26.6	4	.76

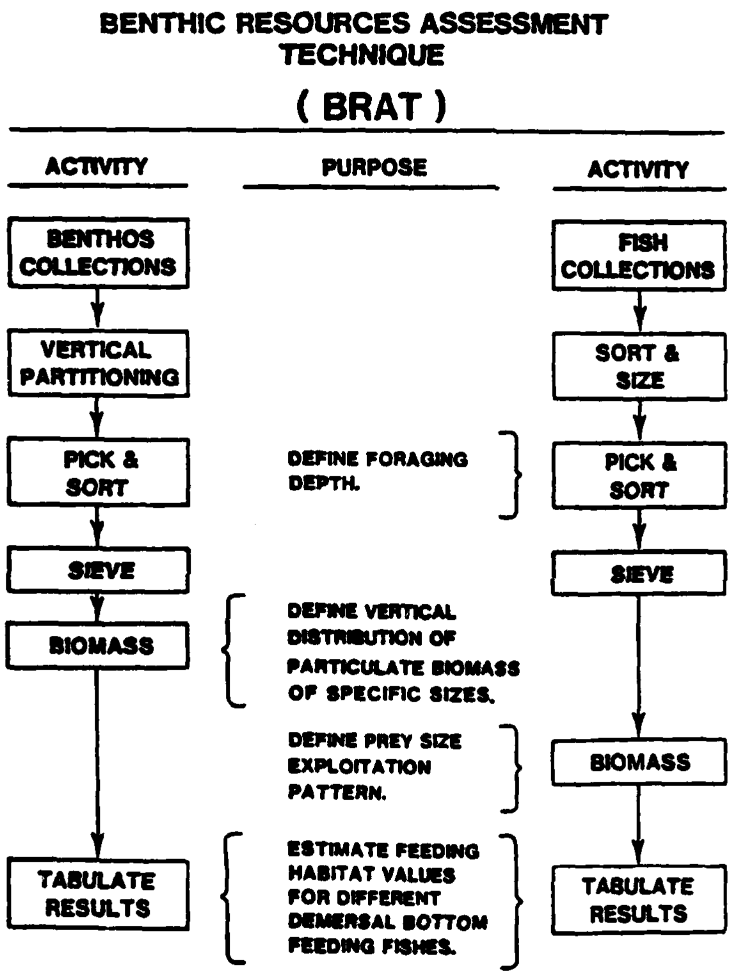


Figure II.9-1 The major steps of the BRAT, up to the statistical and numerical analysis, involved in determining the potential trophic support of a given soft-bottom habitat.

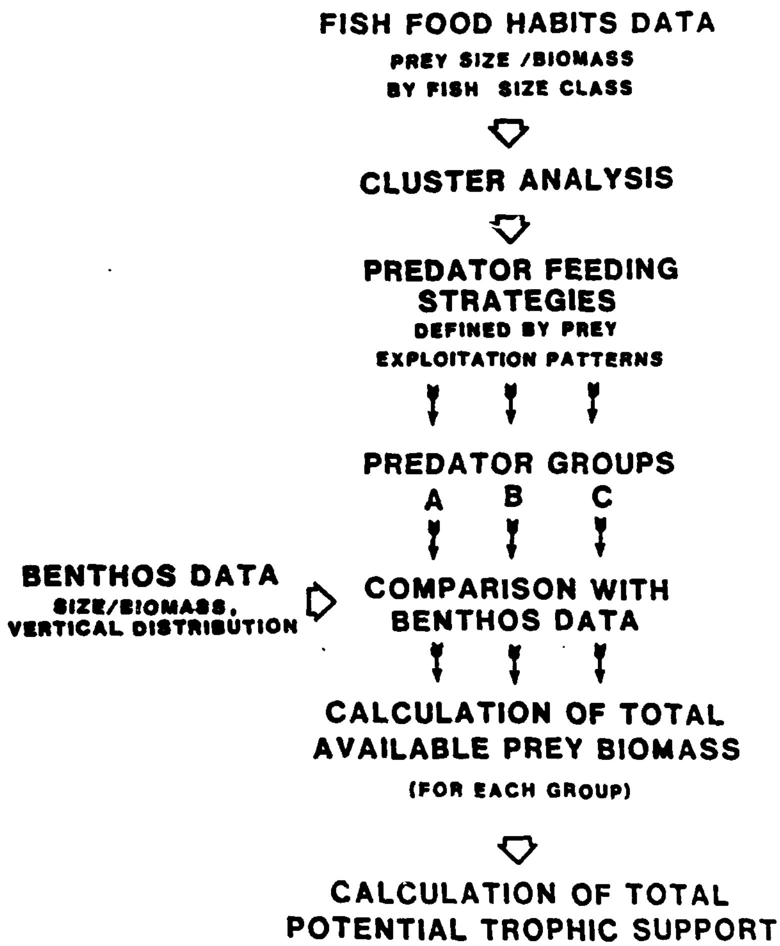


Figure II.9-2 The final steps involved in determining the potential trophic support of a given soft-bottom habitat.

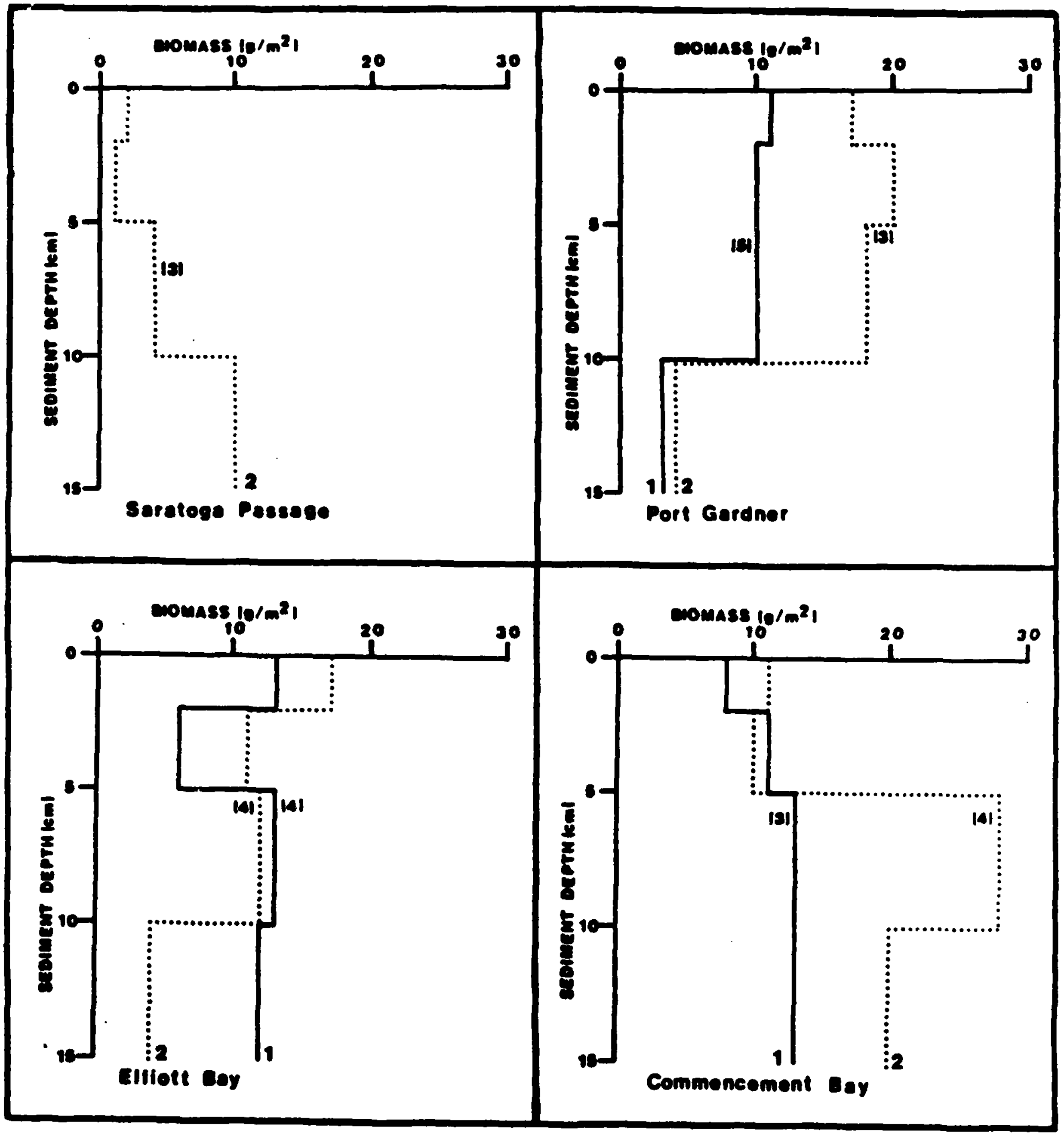


Figure II.9-3 Vertical profiles of biomass within the four ZSFs. In each ZSF the values were averaged in the Priority 1 (solid line) and Priority 2 (dotted line) areas. The number in parenthesis indicates the number of samples used in the average. (Source: adapted from Clarke, 1986)

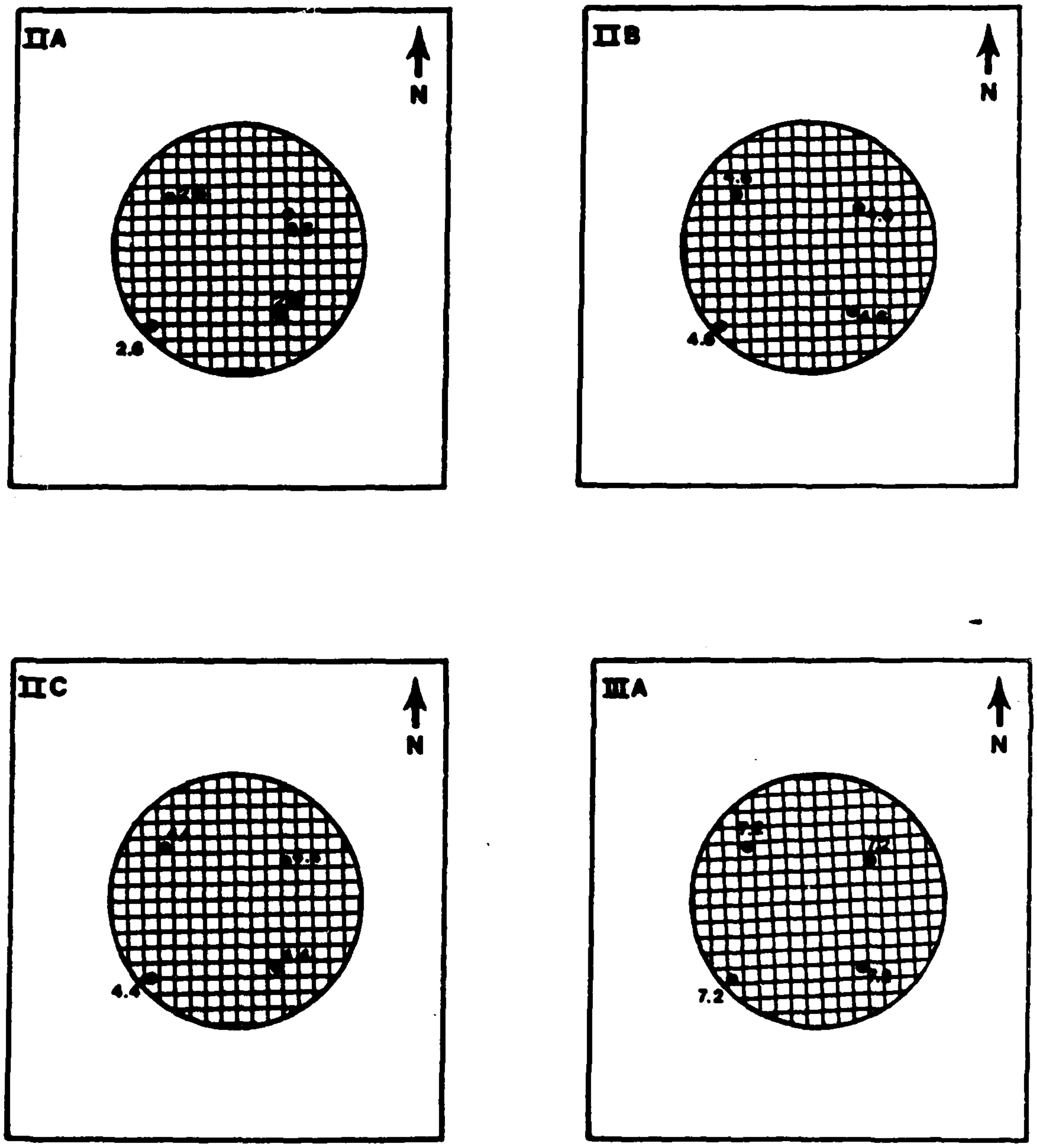


Figure II.9-4 . **Benthic biomass potentially available in Saratoga Passage to four groups of fish (see Table II.9-3 for composition): IIA; IIB; IIC; and IIIA. Units of biomass are in grams per square meter. (Source: adapted from Clarke, 1986)**

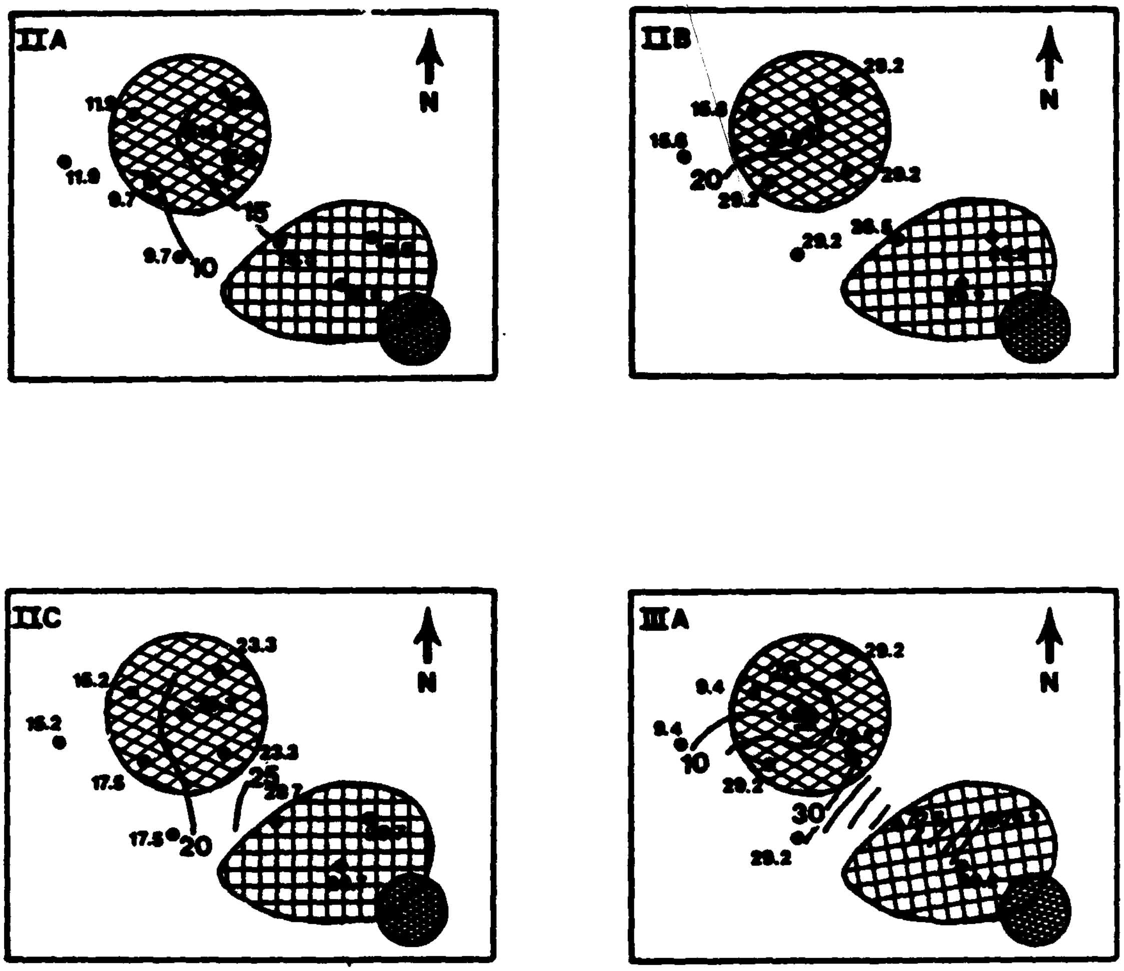


Figure II.9-5 Benthic biomass potentially available in Port Gardner to four groups of fish (see Table II.9-3 for composition): IIA; IIB; IIC; and IIIA. Units of biomass are in grams per square meter. (Source: adapted from Clarke, 1986)

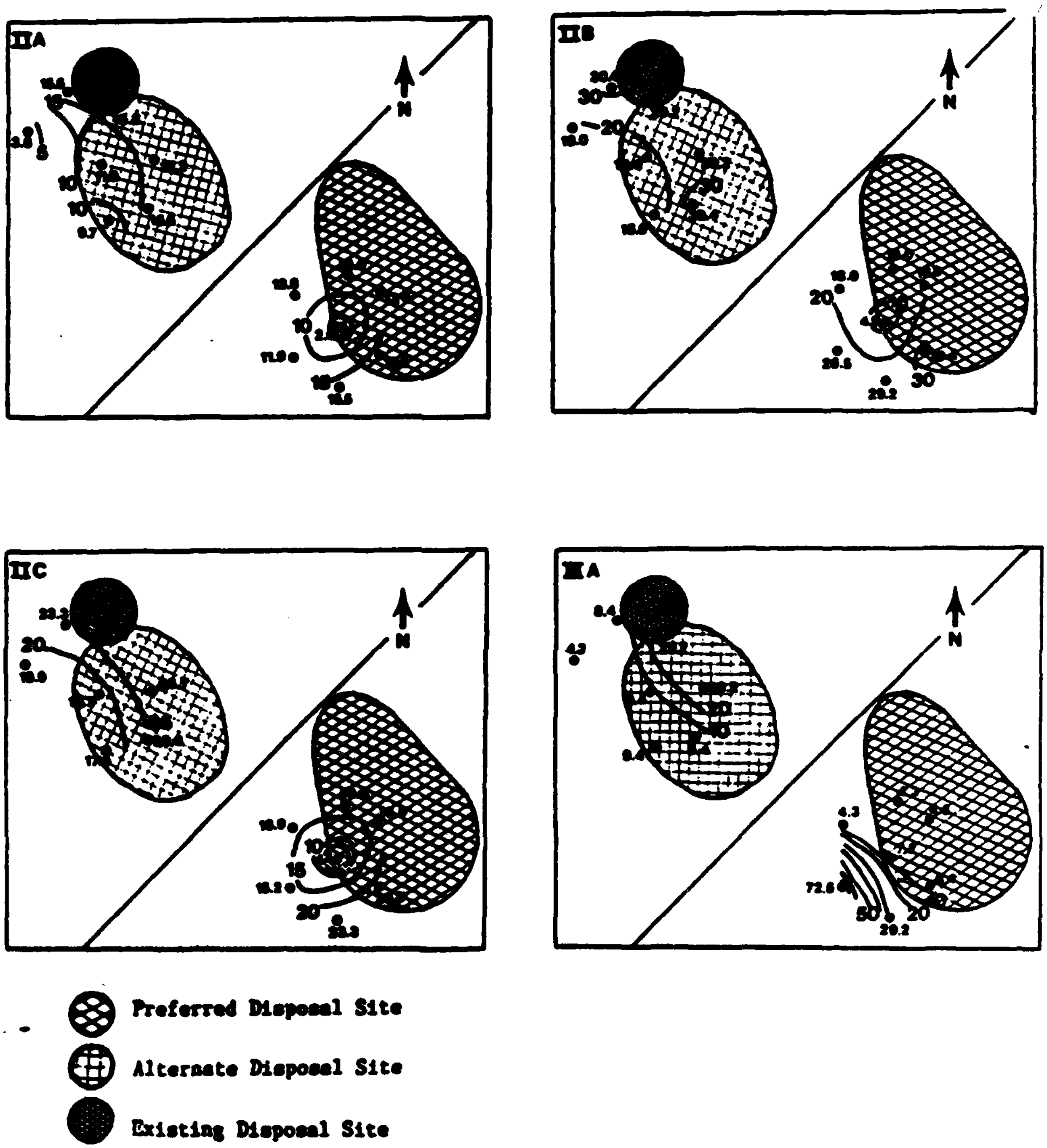


Figure II.9-6 Benthic biomass potentially available in Elliott Bay to four groups of fish (see Table II.9-3 for composition): IIA; IIB; IIC; and IIIA. Units of biomass are in grams per square meter. (Source: adapted from Clarke, 1986)

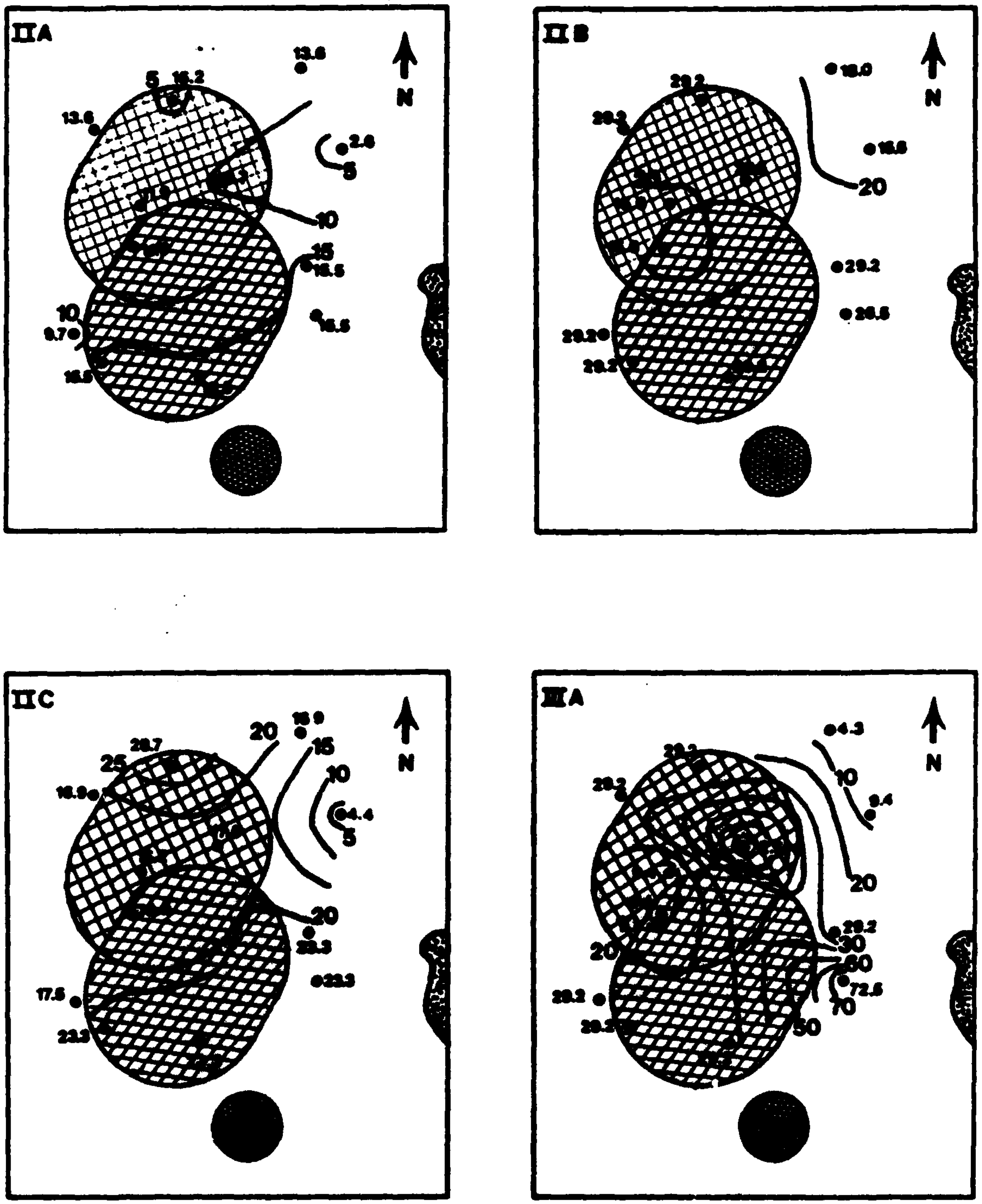


Figure II.9-7 Benthic biomass potentially available in Commencement Bay to four groups of fish (see Table II.9-3 for composition): IIA; IIB; IIC; and IIIA. Units of biomass are in grams per square meter. (Source: adapted from Clarke, 1986)

10. SELECTION OF RECOMMENDED DISPOSAL SITES

The final locations recommended for the disposal sites were determined in two stages. First, the final size and shape of the disposal site was chosen; and second, the chosen size was overlaid on the various maps of hydraulic characteristics, sediments, and biological resources. For each service area, a preferred and an alternate disposal site was chosen.

10.1 Objective

The objective of this chapter is to discuss the size, shape, and locations of the recommended disposal sites. These choices are summarized by overlaying the preferred and alternate disposal sites on the ZSF maps.

10.2 Disposal Site Delineation

The estimated size, orientation, and configuration of the disposal sites were determined by combining results of the numerical dredged material disposal model, sediment depositional analysis, and bathymetric and tidal current data. The disposal model provided estimates of the area over which the material might spread for a single disposal from a barge for varying water depths and current speeds. Using bathymetry and tidal current conditions the appropriate set of dump model results were selected to predict the representative depositional patterns; however, the results represented only the effects of a single barge load of dredge material. An estimate of the deposition pattern that will evolve over a long period of time was calculated by assuming that a large number of barge loads of dredged material will be disposed of randomly throughout an 1800-foot diameter disposal zone. For areas with low tidal currents, the resulting disposal pattern is a circle, concentric with the 1800 foot diameter disposal zone. This circle has a diameter of approximately 4000 feet for depths ranging between 200 and 600 feet. Figure II.10-1 gives a plan and elevation view of the disposal site parameters.

The final orientation and configuration of a disposal site was estimated by considering the depositional analysis and the effects of bottom slope. Table II.10-1 provides the locations of the center of each disposal site; its area, depth and dimensions. Table II.10-2 compares the parameters that were examined in the site specific studies, for the preferred and alternate disposal sites.

10.2.1 Port Gardner--

The Port Gardner preferred disposal site is situated in a depth of 420 feet on a comparatively flat plane (Fig. II.10-2). Bottom slopes are less than one foot of vertical elevation on 200 feet of horizontal distance. Therefore bottom slopes are not expected to influence the shape of the disposal site. Tidal current and depositional analysis data indicate that the site is subject to weak currents. Since the mean speeds near the bottom averaged 0.25 feet per second at the center of the proposed disposal site, the closest disposal model results (400-foot depth and a 0.1 feet per second) current were used to estimate the extent of the disposal site. Because bottom slope and tidal currents should not significantly alter the disposal site configuration, the delineated site is a 4000-foot diameter circle that is concentric with the 1800-foot diameter drop zone.

The Port Gardner alternative disposal site varies from 330 to 425 feet deep. The bottom slopes toward the southwest with an average slope of about one to forty. Low current speeds indicate that the disposal site is depositional. Depositional analysis results are inconclusive as to whether or not this site is depositional, however the median grain size is medium silt which helps to indicate a depositional area. Abundances of both crab and shrimp are low throughout the site which indicates little impact on biological resources.

Approximately one-half of this site may be potentially covered by the site which the U.S. Navy proposes to use for their preferred disposal site to accomodate material from the proposed homeport facility in the east waterway.

10.2.2 Saratoga Passage--

The Saratoga Passage site is a backup alternative site located at a depth of 350 feet. The site is relatively flat with a total variation of eighteen feet (Fig. II.10-3). Current speeds rarely exceed 20 centimeters per second, and this is a low energy area indicating that it is depositional. Depositional analysis and small grain size also support this as a depositional area. Crab were not found in this site and shrimp abundances were relatively low.

10.2.3 Elliott Bay--

The Elliott Bay preferred site is located at a depth of 200-300 feet and is subject to sluggish tidal currents (Fig. II.10-4); therefore, the dredged material disposal model results for a 400-foot depth and a 0.1 feet per second (0.06 knot) current were used to estimate the extent of the material

deposition. The site is located in a submarine valley with relatively steep sides and a downward slope varying between one foot vertical on thirty feet horizontal to one foot vertical on 50 feet of horizontal distance. These bathymetric features probably will play a significant role in determining the size and shape of the disposal area. The anticipated site will be a teardrop-shaped area having a width of approximately 4000 feet and a length of approximately 6000 feet.

The Elliott Bay alternative site is located south of the existing Fourmile Rock disposal zone, and slightly overlaps it. This site lies in 500 feet of water sloping to 600 feet at the southern end. The currents in this site are marginal, being in the neighborhood of the threshold speed of 25 centimeters per second. The depositional analysis shows the southern portion of the site to be depositional and the northern portion is inconclusive. Crab were not found in this site and shrimp were in very low abundance, so that there will be no adverse impacts on resources.

Both sites in Elliott Bay extend outside of the original ZSF boundaries. However, it should be remembered that the selection factors and constraints used to identify the ZSFs, were not considered or applied as inviolate standards. This was because they were being used with existing and available information. As checking studies and site specific studies gathered new information about the ZSFs, adjustments to the boundaries, and later to site lcoations, were made as necessary.

10.2.4 Commencement Bay--

Because of its proximity to Dalco Passage, the Commencement Bay preferred site is located in the most energetic area of the proposed disposal sites (Fig. II.10-5), and it is located in the deepest water (540 to 560 feet). For these reasons, the numerical model results for a simulated 600-foot water depth and 1/2 knot (0.85 feet per second) current were considered most representative of the expected deposition pattern. This pattern was approximately 1,000 feet wide and 1,400 feet long. When the center of this pattern is superimposed randomly throughout the 1800-foot diameter drop zone, the resulting pattern is an ellipse with its long axis of 4600 feet oriented parallel to the tidal current flood-ebb direction and the short axis of 3800 feet. No tidal current data were available at the location of the preferred disposal site; therefore, the flood and ebb currents were determined indirectly from the sediment deposition analysis. The bottom slope is approximately one foot vertical on 200 feet of horizontal distance, and it is not expected to have a significant effect on the disposal site size or orientation.

The Commencement Bay alternative disposal site overlaps the northern one-third of the preferred site, and lies in the same depth range of 540-560 feet. There are no direct current measurements in or near this site, but contours of available data indicate that currents are close to the threshold speed. The depositional analysis is inconclusive in this site. No crab were found and shrimp abundances were low.

10.3 Site Capacity

The size of the disposal site is not affected significantly by the material deposited from any single barge load of material, but is governed by the cumulative effect of many disposals. Disposal model data indicate that the vast majority of the material from each disposal will be deposited in an area measuring approximately 1,000 feet in diameter, or about 20 acres (8 hectares). The overall size of the disposal site is governed by the amount of material being deposited, sediment bulking factors, material characteristics that govern stable side slopes of the disposal mound, effects of bottom slopes, and settlement characteristics. Water depth affects only the initial area of deposition from an individual dump. This area would increase slightly with an increase in water depth, but this increase would not affect the overall site size.

Investigations of existing disposal sites and an evaluation of the dredged material sediment characteristics indicated that mound side slopes of approximately 1:30 were likely (refer to "Technical Supplement to Evaluation of Dredged Material Disposal Alternatives U.S. Navy Homeport at Everett, Washington").

PSDDA estimates of site capacity assume that the shape can be approximated by a truncated cone with a base diameter of 4,000 feet and a diameter at the top of the cone equal to 2,000 feet. A truncated cone with this geometry has a volume equal to approximately nine million cubic yards. It was assumed that bulking effects which take place during dredging and disposal operations will be offset by the long term consolidation of the disposal mound. This assumption equates to a one-to-one ratio of dredged material volume to site capacity volume. Therefore the capacity of a site with a 2,000 foot radius is estimated to be approximately nine million cubic yards. Since all three Phase I sites have a minimum diameter of approximately 4,000 feet, each site can accomodate at least nine million cubic yards within the designated site boundaries. This is two to three times the volume projected for 1985-2000.

10.4 Overlays of the Recommended Disposal Sites with Hydraulic, Sediment, and Biological Characteristics

To complete the description, the disposal sites were overlayed on maps presented earlier describing the ZSFs hydraulic, sediment, and biological characteristics and submerged historic properties.

10.4.1 Port Gardner--

The Port Gardner preferred and alternate disposal sites were superimposed on maps of hydraulic characteristics (Figs. II.10-6 through II.10-8), sediment characterisitics (Figs. II.10-9 through II.10-13), and biological resources (Figs. II.10-14 through II.10-16).

Field data collected near the center of the preferred disposal site showed that the peak (1%) speed near the bottom lay below the threshold for the movement of newly deposited material (Fig. II.10-6; PSDDA current study, 1986). At this location the total variance of the currents was 74 cm2/sec2 and the 1% fastest speed was only 8 centimeters per second. The WES tidal model also indicates that the site lies in a zone of weak tidal currents (Fig. II.10-7). Maps of sediment characteristic show that the site is located in an area of high clay content and where the 95% confidence limits are exceeded for total volatile solids, biological oxygen demand, and water content (Figs. II.10-9 through II.10-13). The site thus appears to be depositional in character. With respect to biological resources, the site is located in an area where populations of crab have not exceeded 100 crab per hectare and the population of shrimp has not exceeded 250 shrimp per hectare (Figs. II.10-14 and II.10-16).

For the approximately 1% of the dredged material that remains suspended for some time in the water column the prevailing currents indicate that this sediment will be transported northward or westward away from areas of high crab and shrimp populations (compare Figs. II.10-8, II.10-14, and II.10-15).

No submerged historic properties were identified at this site through literature and sonar reconnaissance.

Since an acceptable disposal site was found in Port Gardner, no further consideration was given to locating a site in the alternate ZSF in Saratoga Passage.

10.4.2 Elliott Bay--

The Elliott Bay preferred and alternate disposal sites were superimposed on maps of hydraulic characteristics (Figs. II.10-17 through II.10-21), sediment characteristics (Figs. II.10-22

through II.10-26), and biological resources (Figs. II.10-27 through II.10-29).

The maps of current strength indicate that the Fourmile Rock ZSF lies across a strong gradient of tidal currents (Figs. II.10-17 through II.10-20). In the eastern portion, the current variance averaged over the water column (Fig. II.10-17) and that near the water surface is on the order of 50 cm2/s2. In the western portion, the variance increases by approximately twofold to 100 cm2/s2. From the correlations between rms and peak speeds described earlier, these variances correspond to 1% fastest speeds of 20 centimeters per second (for 50 cm2/s2 variance) and 27 centimeters per second (for 100 cm2/s2 variance).

One of the PSDDA current meter moorings was placed in the existing disposal site near the age-dated core mentioned earlier. The 1% fastest speed equalled 27 centimeters per second and the analysis of the age dated core suggested that some dredged material had been eroded from the upper part of the core. This speed is approximately equal to the 25 centimeters per second threshold speed at which dredged material begins to be resuspended. These results suggest that the western portion of the Fourmile Rock ZSF is sufficiently energetic that dredged material could be eroded. In the eastern portion of this ZSF the 1% speeds are estimated to be less than 20 centimeters per second which is below the threshold for initiation of dredged material mound erosion.

The western portion of the ZSF appears to have lower volatile solids, biological oxygen demand, percent water, and coarser sediments than in the eastern portion (Figs. II.10-22 through II.10-26). Although the sediment patterns may have been altered by previous disposal operations, these variations may reflect the increased current strength between the eastern and western parts of the ZSF.

The Fourmile Rock ZSF was not chosen as the preferred disposal site because: 1) the possibility of erosion mentioned earlier in this chapter; 2) public concerns about this site; and 3) a site was found in inner Elliott Bay where disposed materials will not be eroded, as described below. Also, public input during the DSWG meetings favored the inner Elliott Bay disposal site.

An extensive study of the experimental disposal site located within the inner Elliot Bay ZSF indicated that dredged material was not eroded over a several-year period (Section II.7.2.1). This conclusion is supported by the PSDDA hydraulic and sediment studies. The total current variance in the disposal site is less than 30 cm2/s2 (Fig. II.10-17), the 1% peak speeds are less than 15 centimeters per second (Fig. II.10-18), and the numerical model indicates very weak tidal currents

(Fig. II. 10-19). The 1% peak speeds lie well below the 25 centimeter per second threshold and apparently are insufficient to resuspend dredged material.

The sediment characteristics show that the 95% confidence limits were exceeded over most of the site for volatile solids, biochemical oxygen demand, and water content; and the area has very fine grained sediment (Figs. II.10-22 through II.10-26). Sediment cores indicate that sediments deposit at the rate of approximately one centimeter per year (Lavelle et al., 1986). Because approximately a decade has elapsed since the experimental disposal operation in 1976, on the order of ten centimeters of sediment should overlie the capped dredged material deposit; therefore, the PSDDA sediment analysis, which utilized the upper two centimeters, should not have affected the integrity of the cap of experimental disposal operation.

Taken together, the results of the experimental disposal, the hydraulic characteristics, and the sediment characteristics indicate that dredged material deposited in the inner Elliott Bay disposal site will not be resuspended by local currents.

No crab were found within the disposal site during the three cruises (February, June, and September, 1986; Fig. II.10-27). Highest abundance of shrimp observed was 370 per hectare in September (Fig. II.10-28). These quantities indicate that crab and shrimp are not found in commercial quantities within the proposed disposal site.

The prevailing currents, as indicated by net current speed and direction, are directed toward the head of Elliott Bay near the bottom in the recommended disposal site (Fig. II.10-19). Because of the low animal populations, the suspended sediment carried by the prevailing currents is expected to have minimal impact on the biological resources.

Significant historical properties were found by side scan sonar in Elliott Bay. Exhibit C discusses actions to avoid impacts to these resources.

10.4.3 Commencement Bay--

The Commencement Bay preferred and alternate disposal sites were superimposed on maps of hydraulic characteristics (Figs. II.10-30 through II.10-33), sediment characteristics (Figs. II.10-34 through II.10-38), and biological resources (Figs. II.10-39 through II.10-41).

No submerged historic properties were identified at this site through literature search and sonar reconnaissance.

This disposal site lies near a sharp gradient in the strength of tidal currents (Fig. II.10-33). Contours constructed from the hydraulic model indicate a total variance of approximately 100 cm^2/s^2 near the water surface (Fig. II.10-32). This corresponds to a 1% peak speed of 27 centimeters per second based on the linear regression presented earlier. The WES numerical tidal model indicates a peak speed, as averaged over the water column for an extreme spring tide, of 20 centimeters per second (Fig. II.10-31). However, neither of these

estimates have substantial uncertainties because they may not be representative of conditions near the bottom. There are no direct current measurements in the vicinity of the disposal site. For these reasons the choice of a disposal site location was guided primarily by the depositional analysis results, and the patterns of sediment characteristics.

The preferred disposal site lies in an area where the sediment properties are anomalous, suggesting that here the sediments tend to deposit rather than erode. In this area the percentage clay is elevated above 15%, the water content exceeds 50%, the volatile solids exceed 4%, and the biochemical oxygen demand exceeds 500. As the area does not generally exceed the 95% confidence limits, the small grain size suggests that the current speeds lie below the 25 centimeters per second threshold; thus, the bottom speeds in the disposal site may be portrayed by the numerical model which gives a peak speed of 18 to 20 centimeters per second. At this speed, disposal materials should not be resuspended by local currents. With respect to biological resources, no crab were found within the disposal site, and shrimp were in low abundance.

Although the prevailing currents were not measured in the vicinity of the disposal site, the shape of the percent clay contours (Fig. II.10-38) indicates that the net currents flow toward the southwest. Because of the low animal populations the suspended sediments carried in this direction from the disposal site are not expected to have an unacceptable adverse impact on biological resources.

10.5 Conclusions

In conclusion, the three preferred disposal sites are judged to lie in depositional areas because: 1) the peak speeds lie below the threshold speed for movement of fine grained, recently deposited dredged material; 2) the sediment characteristics show fine grained material and statistically elevated water content, biochemical oxygen demand, and volatile solids, and 3) the quantities of crab and shrimp are low. The maximum densities of crab and shrimp observed thus far in PSDDA are 496 crab and 1760 shrimp per hectare (in Port Gardner; September, 1986). In contrast, between 0-19 crab and 25-300 shrimp per hectare were found in the preferred disposal sites. In other words, these concentrations equal 4% and 17% of the maximum seen in Port Gardner. Moreover, the number of crab lie below the 100 per hectare threshold below which the crab populations are considered minimal. These percentages suggest that there are small populations of crab and moderate populations of shrimp in the proposed disposal sites.

Even though some disposed dredged material will be transported beyond the disposal site boundaries, the ratio of the natural sedimentation to the escaped material exceeds 100:1. Consequently the escaped material will be substantially diluted with natural sediments. Considering the low animal populations downstream from the disposal sites, the acceptable nature of the dredged material, natural sedimentation, and the substantial dilution, the dredged material that does escape from the disposal sites is not expected to have a measureable impact on the animal population within the embayments containing the disposal sites.

TABLE II.10-1 INFORMATION ON THE PREFERRED AND ALTERNATIVE DISPOSAL SITES.

	Latitude	Longitude	Area (acre)	Depth (ft)	Dimensions (ft)
Saratoga Passage					
Alternate	48° 5.43	122° 27.35	318	350	4200
Port Gardner					
Preferred	47° 58.86	122° 16.67	318	420	4200
Alternate	47° 58.26	122° 15.55	375	330-425	3800 x 5833
Elliott Bay*					
Preferred	47° 36.03	122° 21.34	415	200-360	6200 x 4000
Alternate	47° 37.09	122° 24.85	480	500-600	4500 x 6000
Commencement Bay					
Preferred	47° 18.22	122° 27.84	310	540-560	4600 x 3800
Alternate	47° 18.72	122° 27.95	310	540-560	4600 x 3800
*Adjusted Preferred Elliott Bay Site	47° 35.97	122° 21.38	415	300-360	6200 x 4000

TABLE II.10-2 COMPARISON OF SITE SELECTION FACTORS FOR PREFERRED AND ALTERNATE DISPOSAL SITES

	STATISTICALLY ELEVATED					CURRENTS				
	VOLATILE SOLIDS	BIOCHEMICAL OXYGEN DEMAND	WATER CONTENT	GRAIN SIZE	PERCENT CLAY	TOTAL VARIANCE (cm s)	PEAK SPEED MODEL (cm/s)	CRAB * MALE (#/Hectare)	CRAB * FEMALE (#/Hectare)	SHRIMP * (#/Hectare)
Saratoga Passage										
Alternate	Yes	Yes	Yes	Med-Fine Silt	15%	200	20	0	0	62
Port Gardner										
Preferred	Yes	Yes	Yes	Medium Silt	15%	74-100	8	0	30	43
Alternate	Yes	No	No	Medium Silt	10-15%	105	2-8	0	28	76
Elliott Bay										
Preferred	Yes	Yes	Yes	Coarse Silt	12%	18	1	0	0	328
Alternate	No	Yes	No	Coarse Silt	12%	50-100	10	0	0	215
Commencement Bay										
Preferred	Yes	Yes	No	Coarse Silt	15%		20	0	0	56
Alternate	Yes	No	No	Coarse Silt	10-15%		20-40	0	0	44

* These numbers are the highest average beam trawl catches for all sample periods.

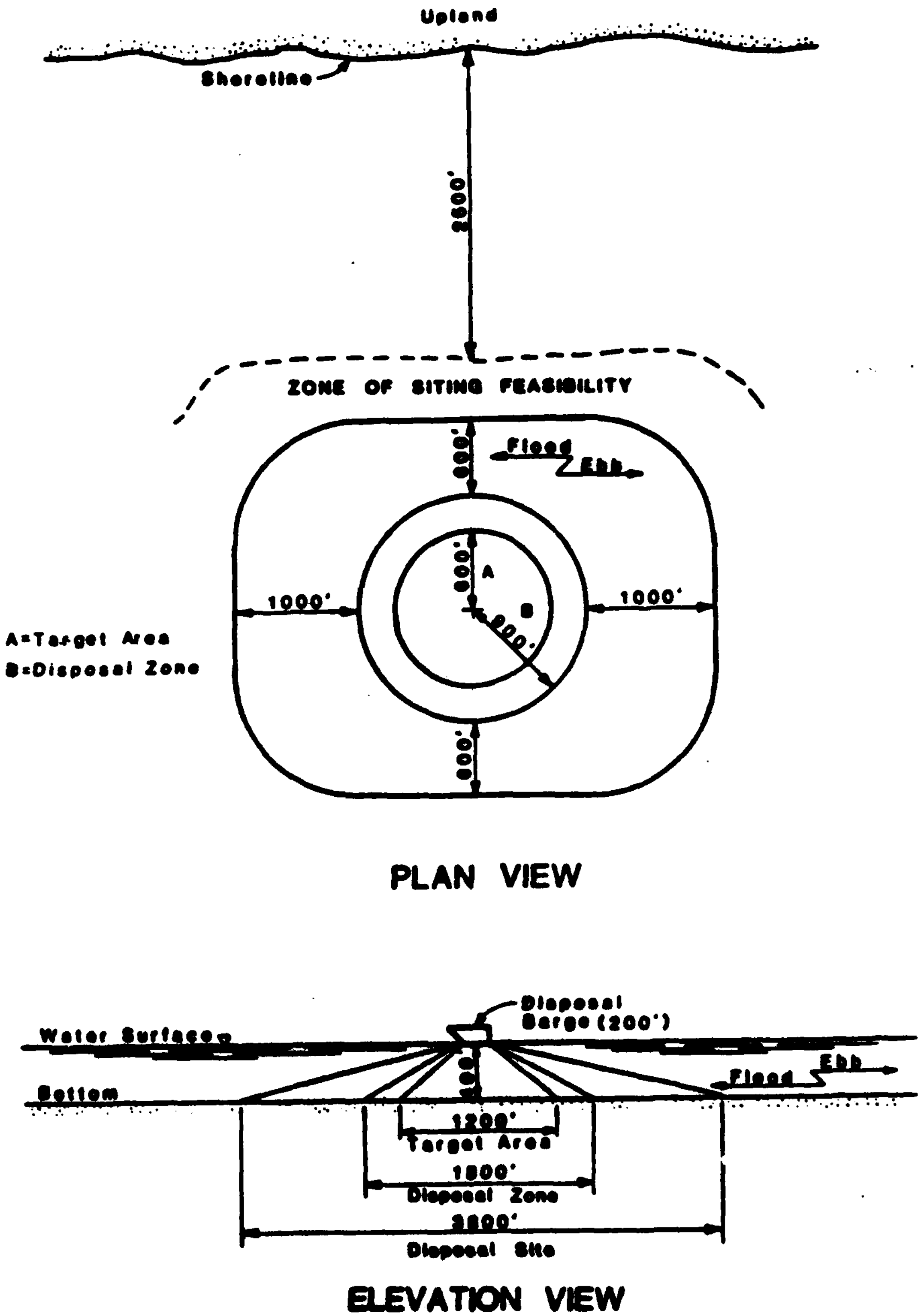


Figure II.10-1 Typical disposal site parameters.
(Source: Corps)

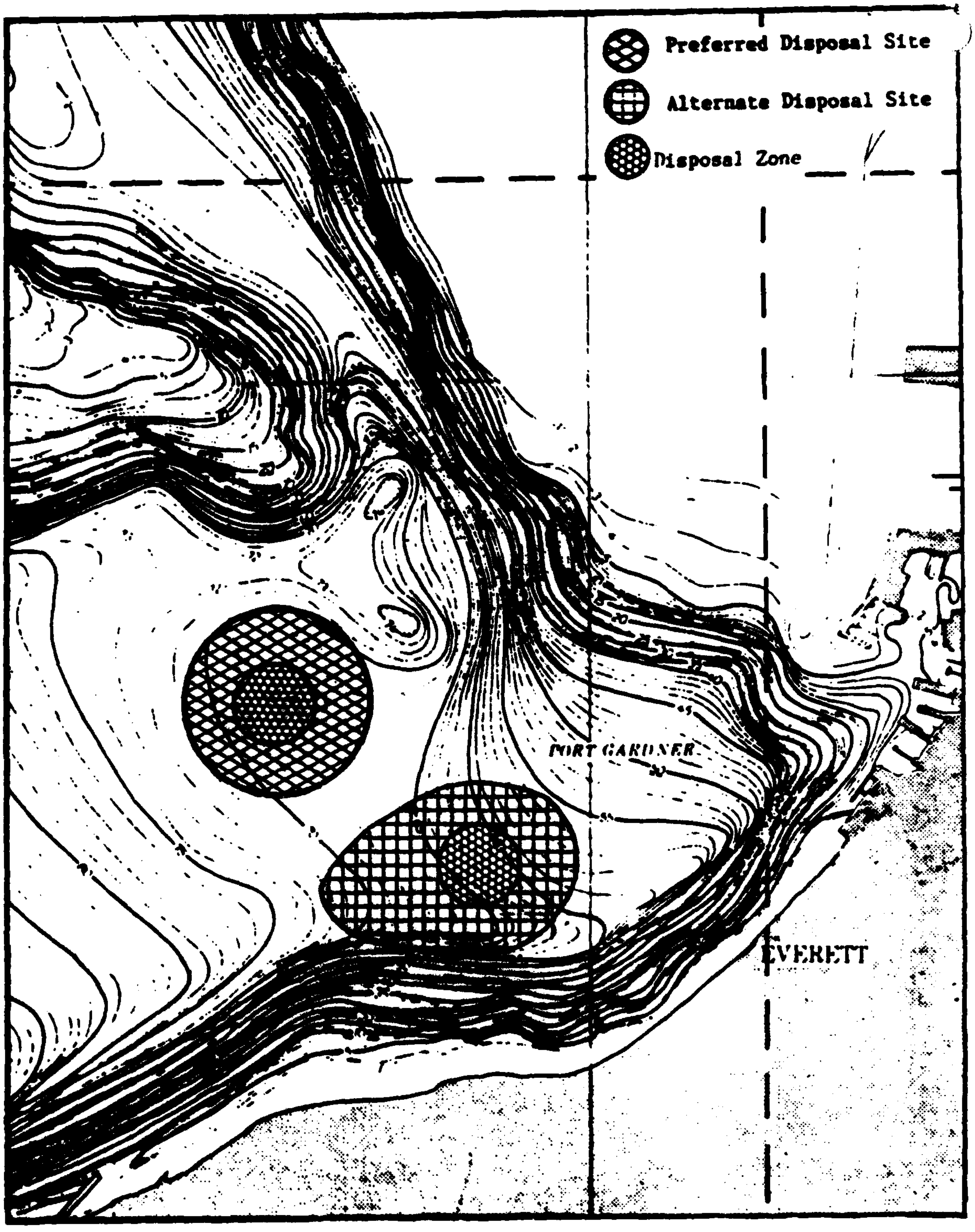


Figure II.10-2 Preferred and alternative disposal sites in Port Gardner superimposed on bathymetry at one fathom intervals.

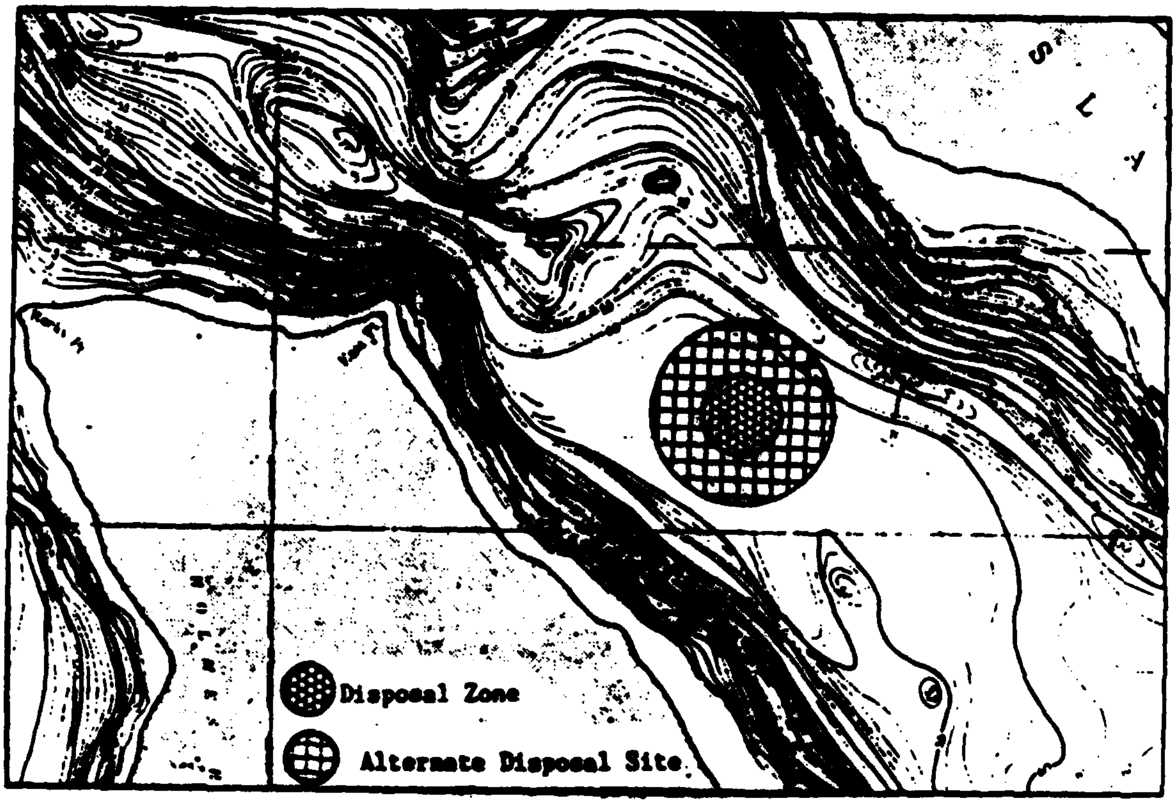


Figure II.10-3 Alternative disposal site in Saratoga Passage superimposed on bathymetry at one fathom intervals.

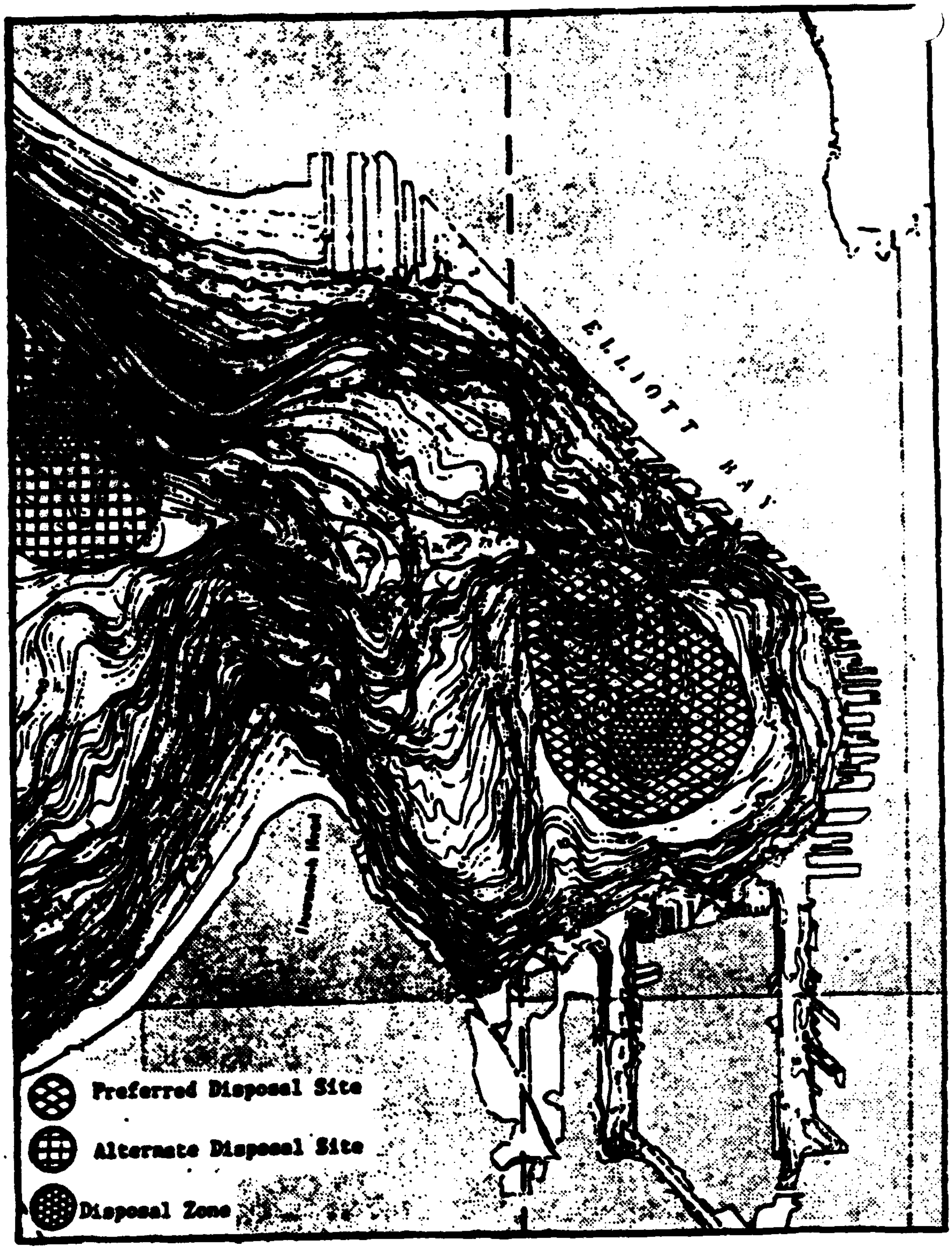


Figure II.10-4a Preferred and alternative disposal sites in Elliott Bay superimposed on bathymetry at one fathom intervals.

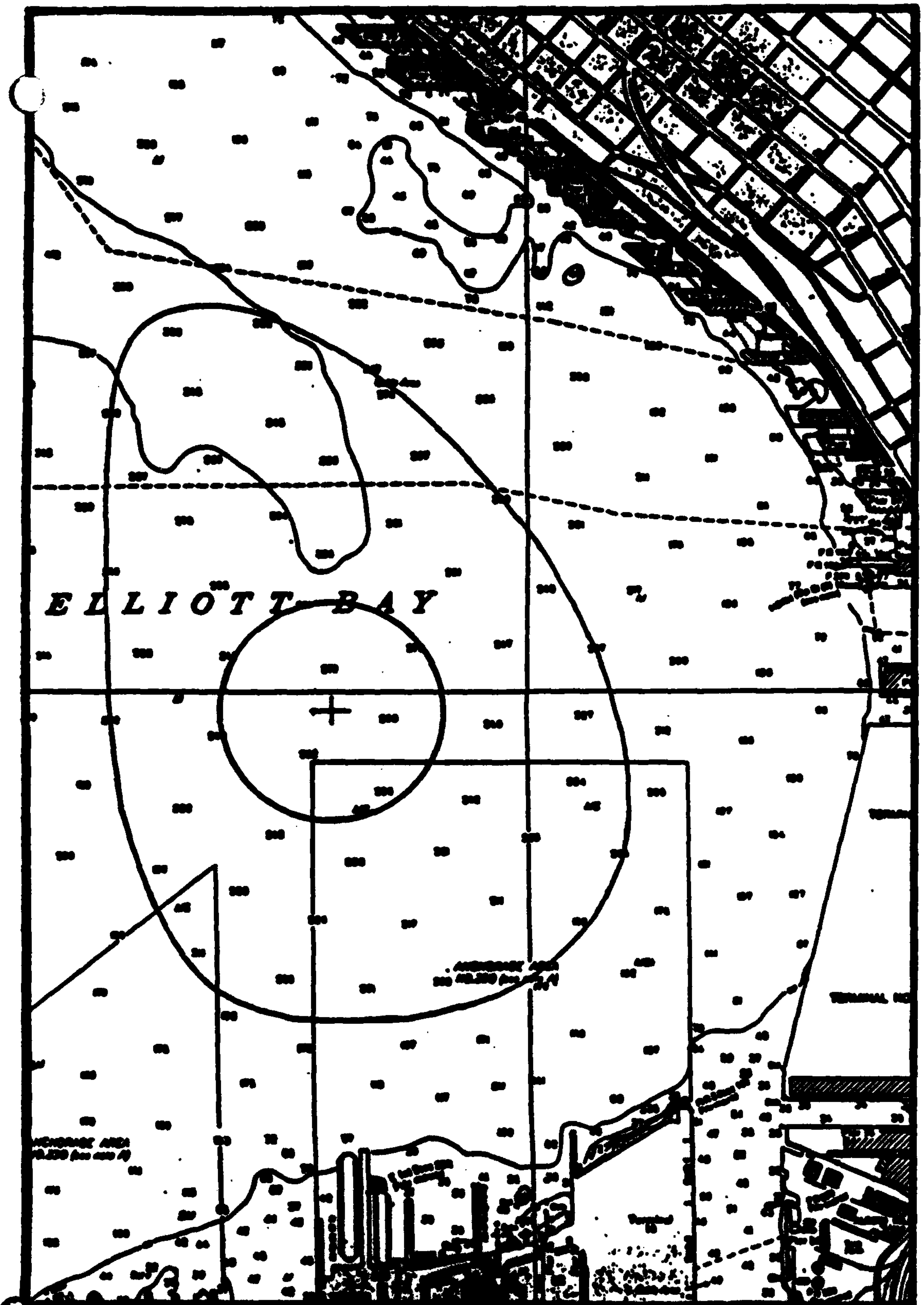


Figure II.10-4b Elliott Bay preferred disposal site, showing adjustment to disposal zone, a displacement of 375' to the SSW from that shown in Figure II.10-4a. As described in Exhibit C, this adjustment changed only the zone, not the site boundary, and was undertaken to avoid potentially significant shipwrecks.

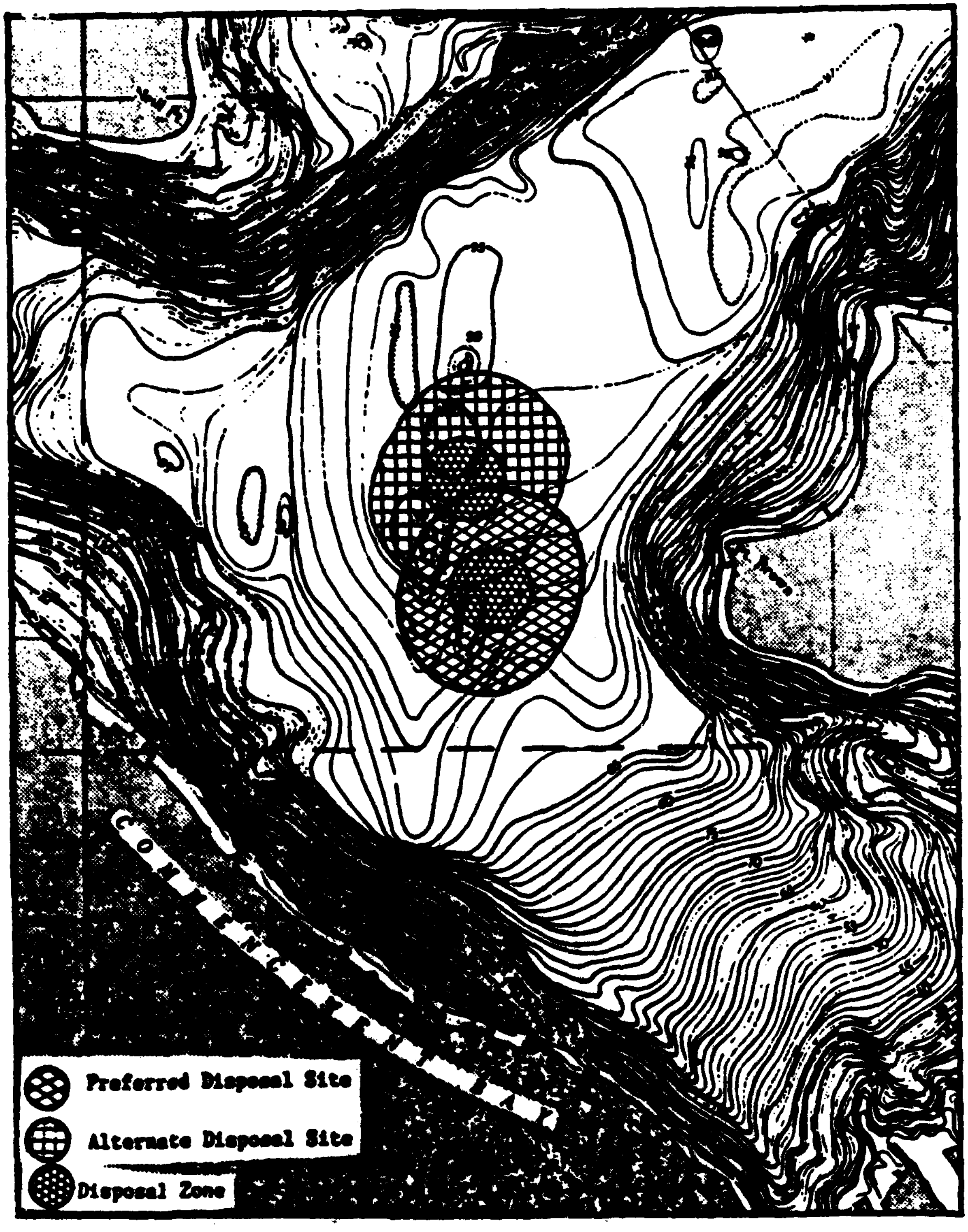


Figure II.10-6 Preferred and alternative disposal sites in Commencement Bay superimposed on bathymetry at one fathom intervals.

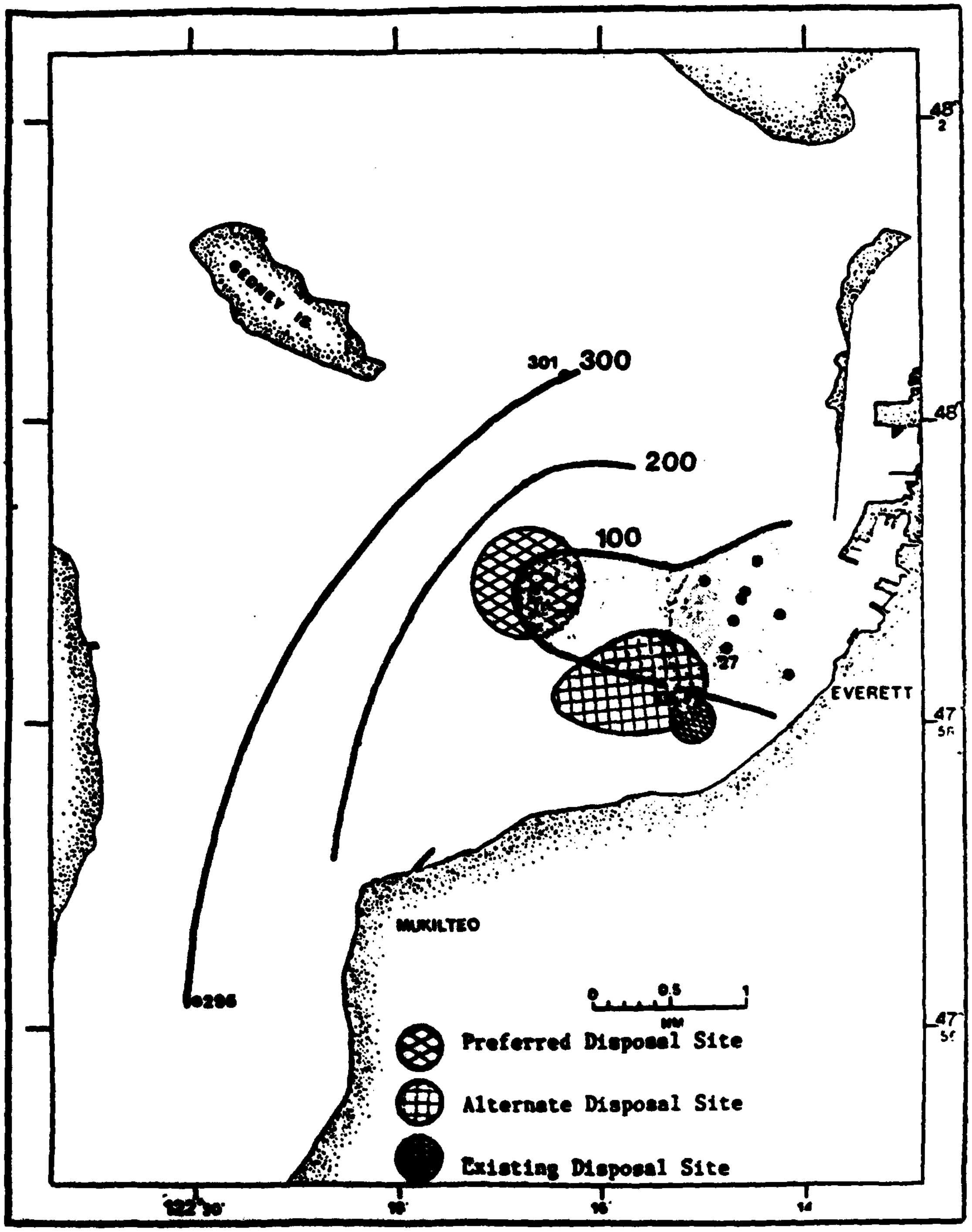


Figure II.10-6 Preferred and alternative disposal sites in Port Gardner on contours of total variance ($cm^2 s^{-2}$) of the currents averaged over the water column. (Source: ENI)

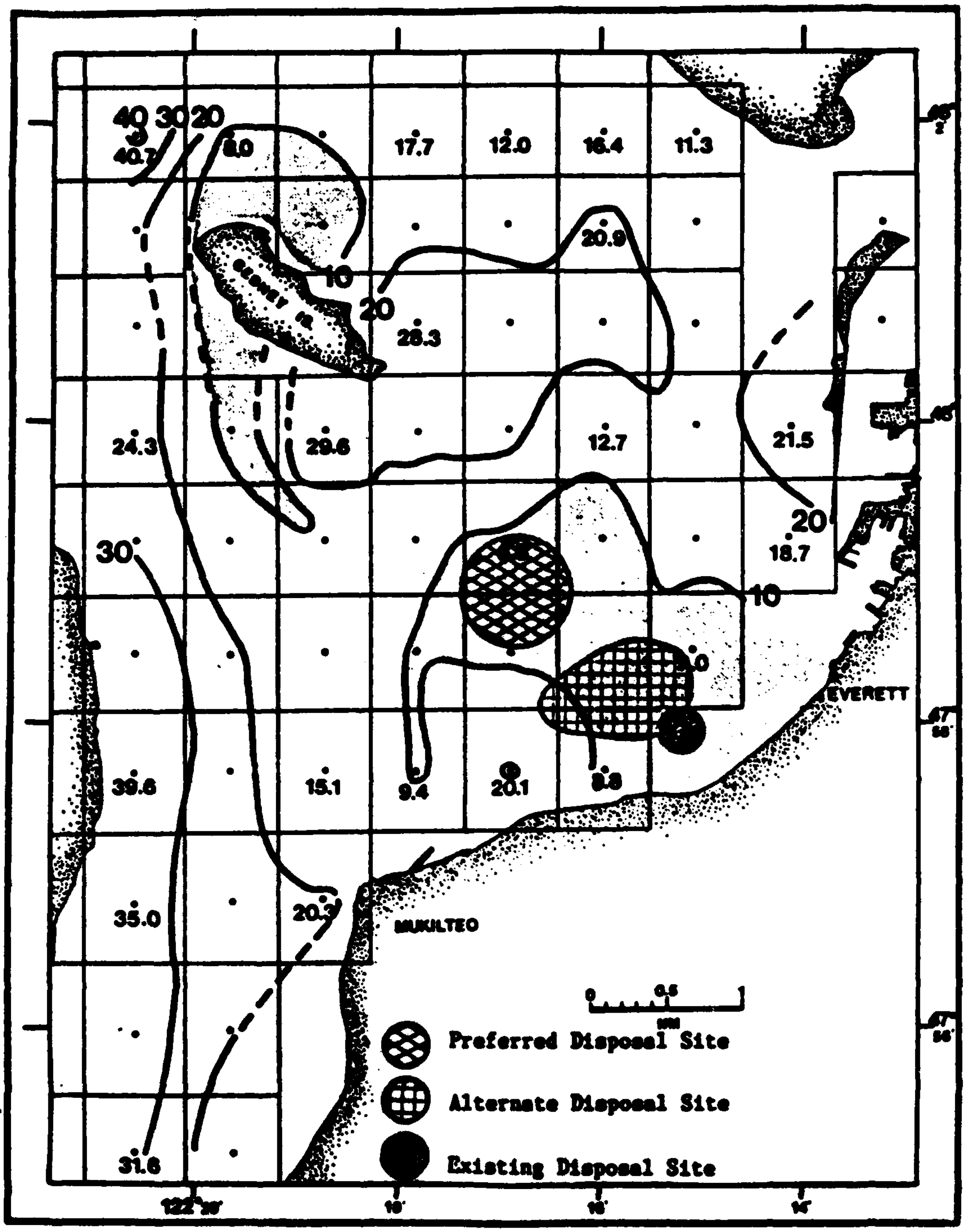


Figure II.10-7 Preferred and alternative disposal sites in Port Gardner on contours of peak speeds (cm/s) for the extreme spring tide from the numerical tidal model.

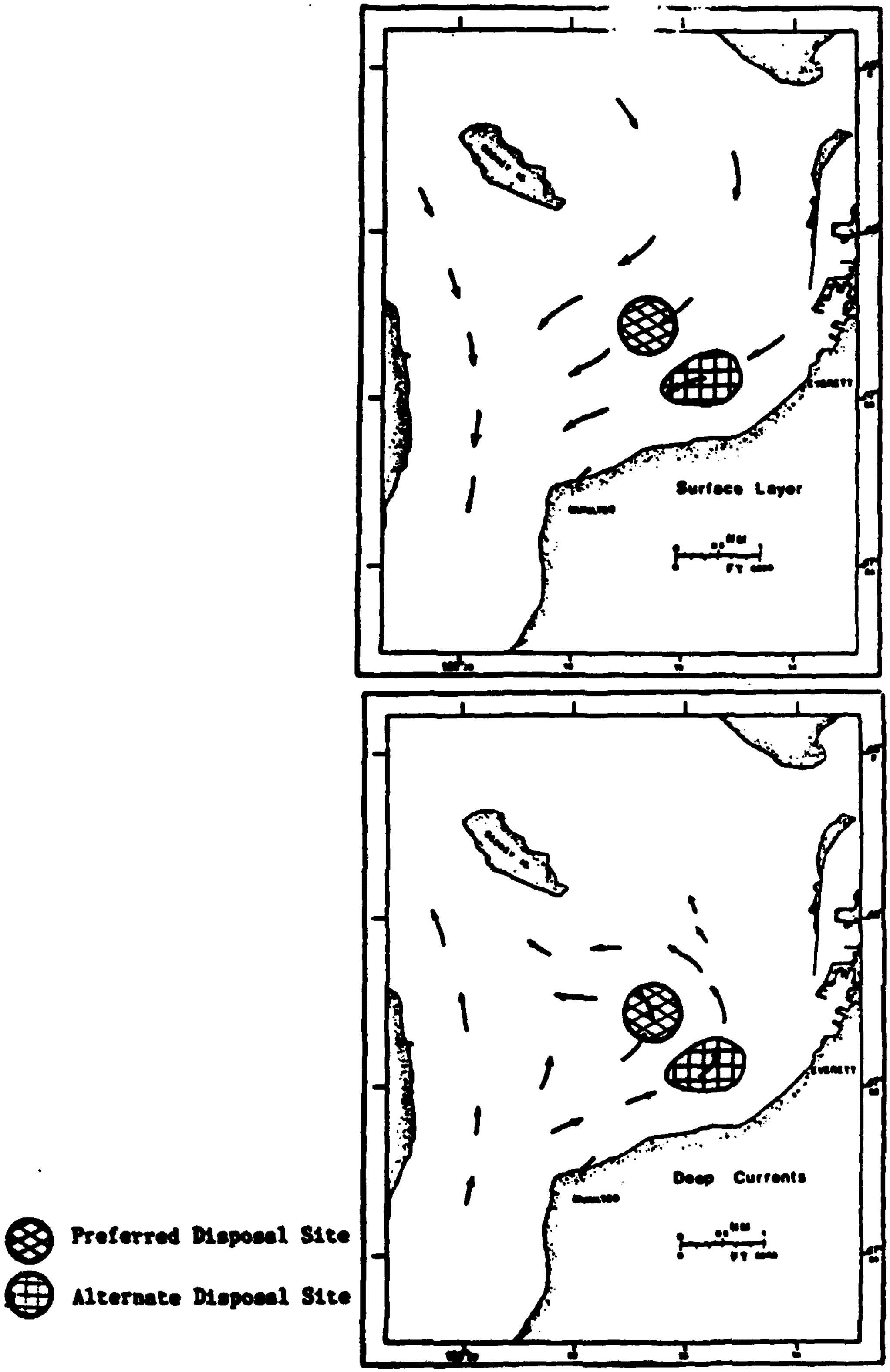


Figure II.10-8 Estimated pattern of prevailing currents in Port Gardner for the A) shallow surface layer and the B) deeper layer. (Source: EHI)

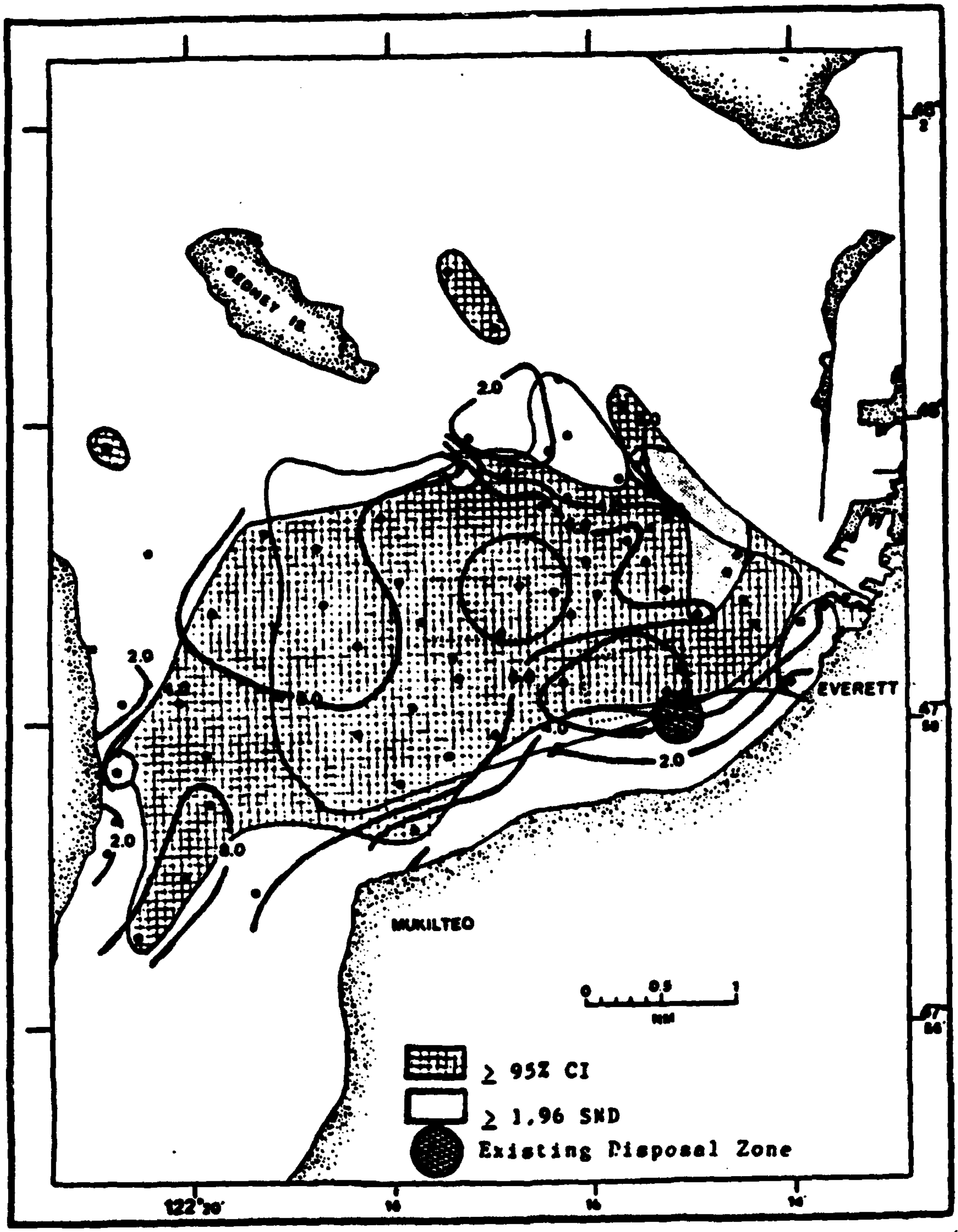


Figure II.10-9 Preferred and alternative disposal sites in Port Gardner on contours of total volatile solids with areas exceeding the 95% CI and 1.96 SND.

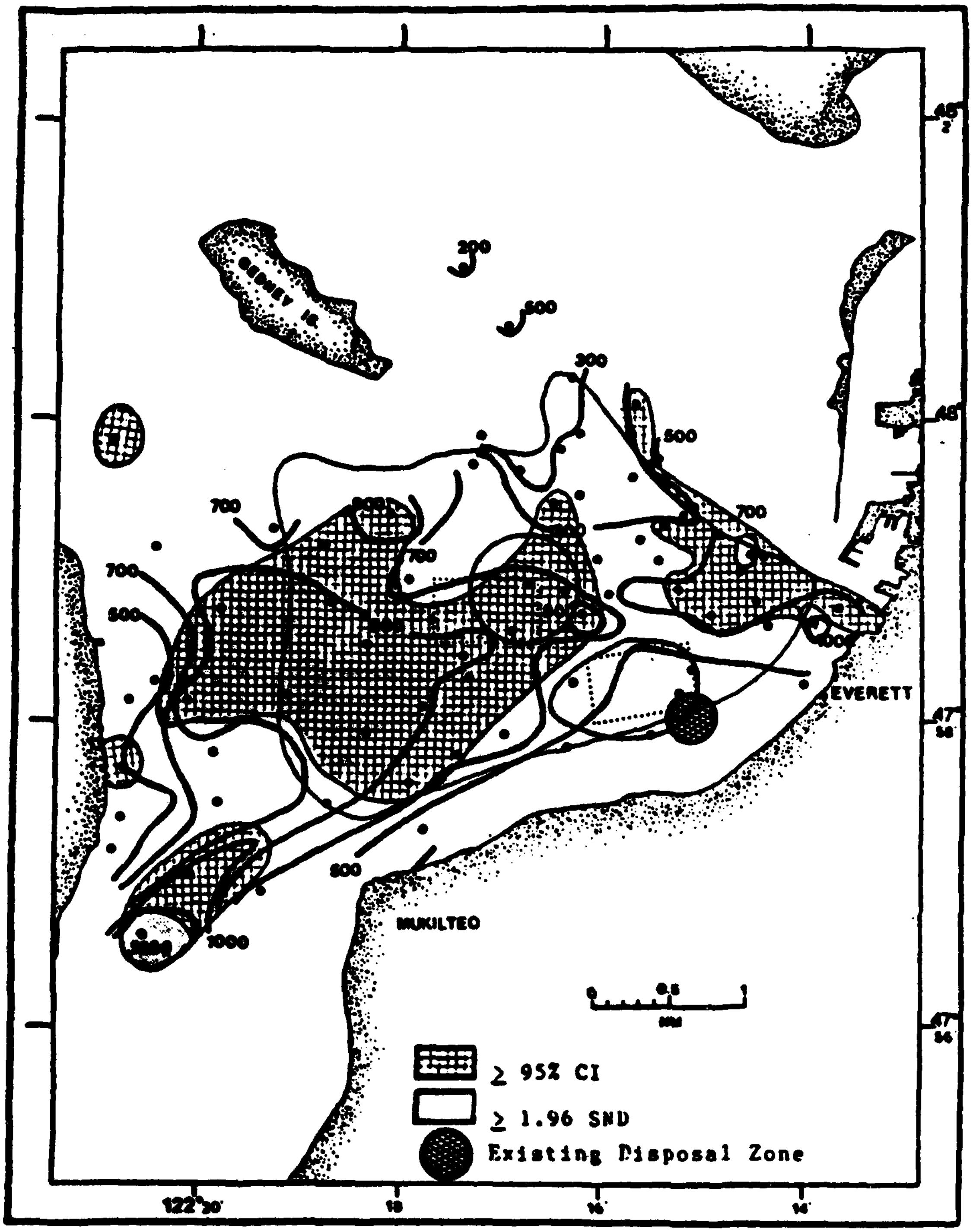


Figure II.10-10 Preferred and alternative disposal sites in Port Gardner on contours of BOD with areas exceeding the 95% CI and 1.96 SND.

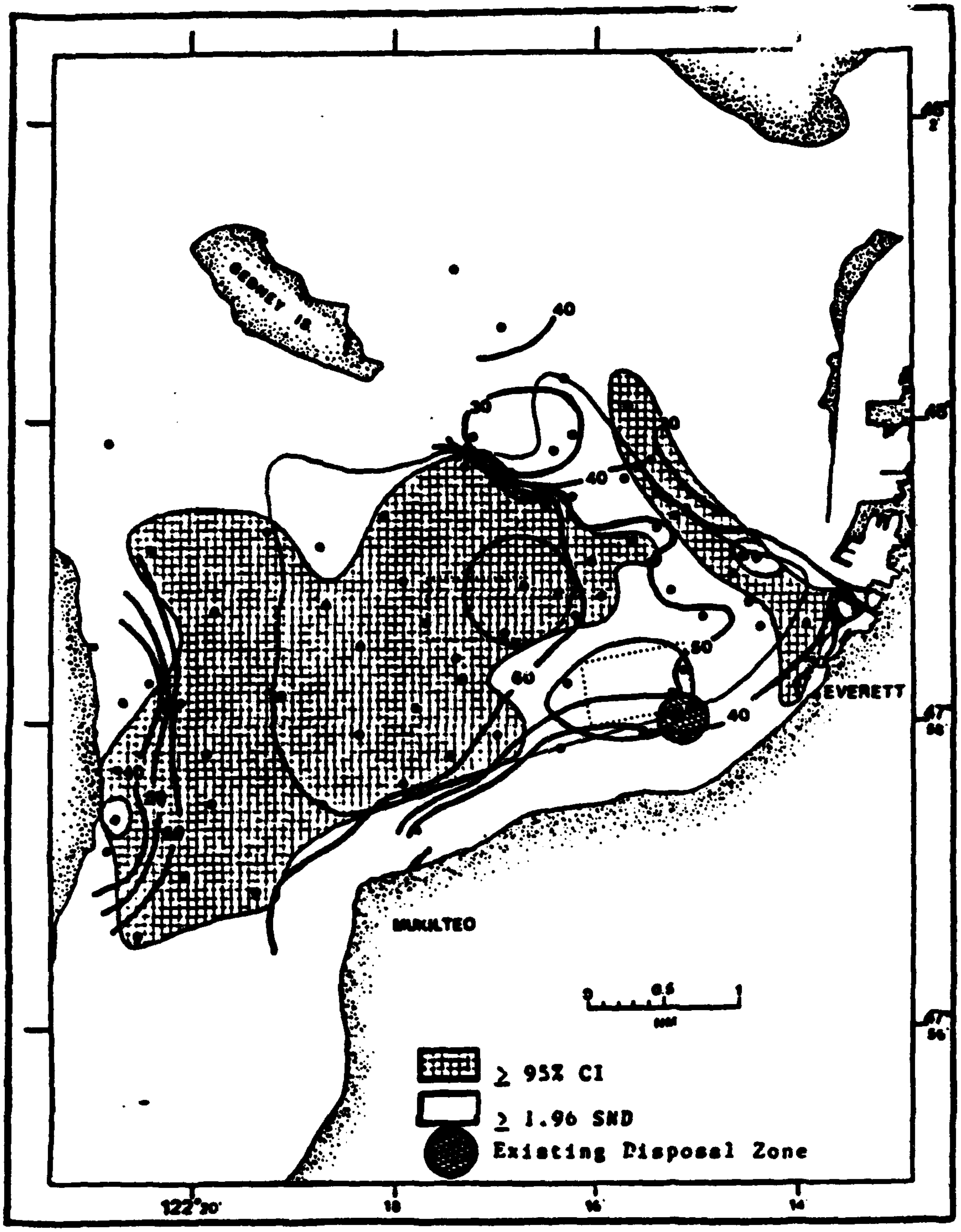


Figure II.10-11 Preferred and alternative disposal sites in Port Gardner on contours of percent water with areas exceeding the 95% CI and 1.96 SND.

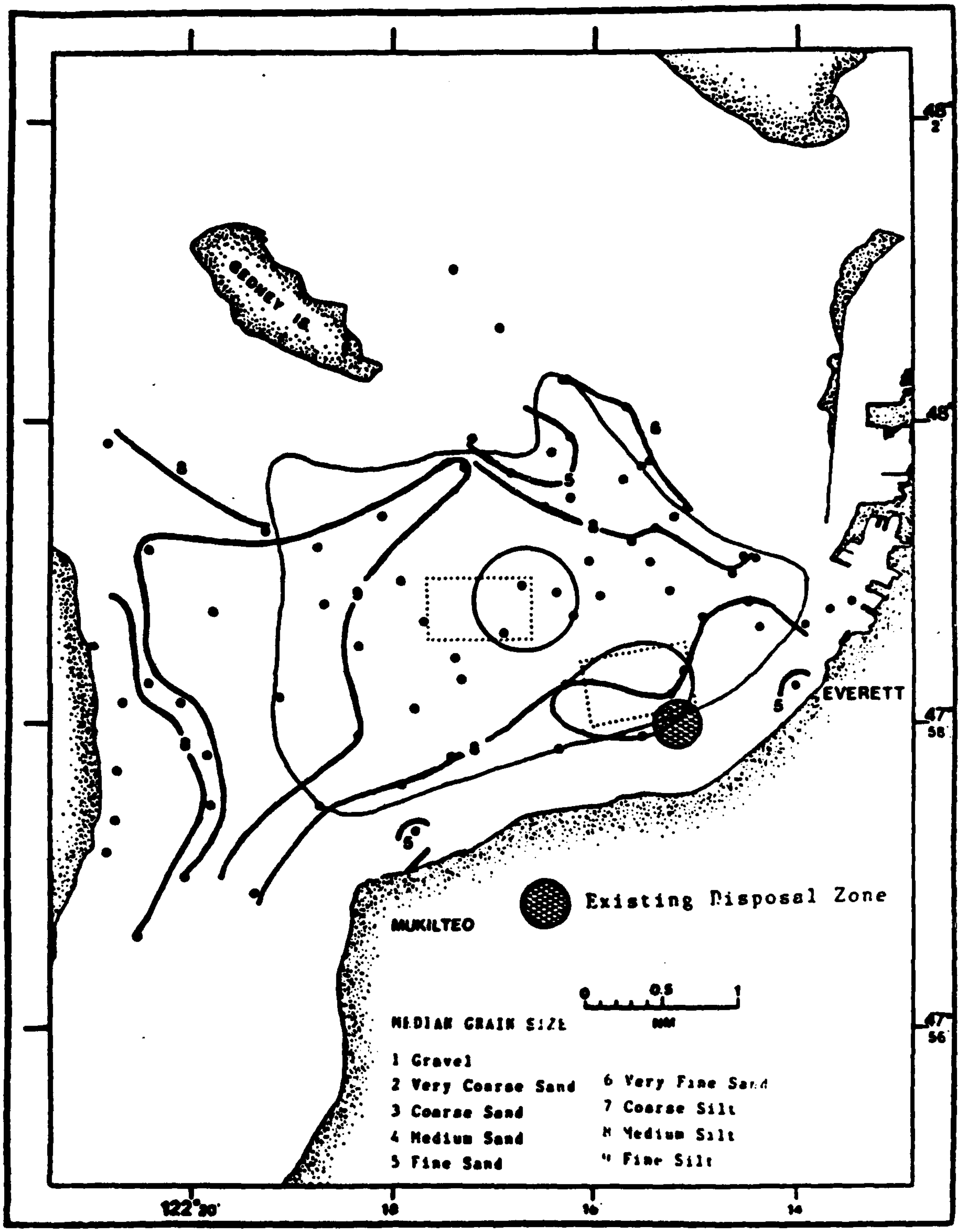


Figure II.10-12 Preferred and alternative disposal sites in Port Gardner on contours of grain size.

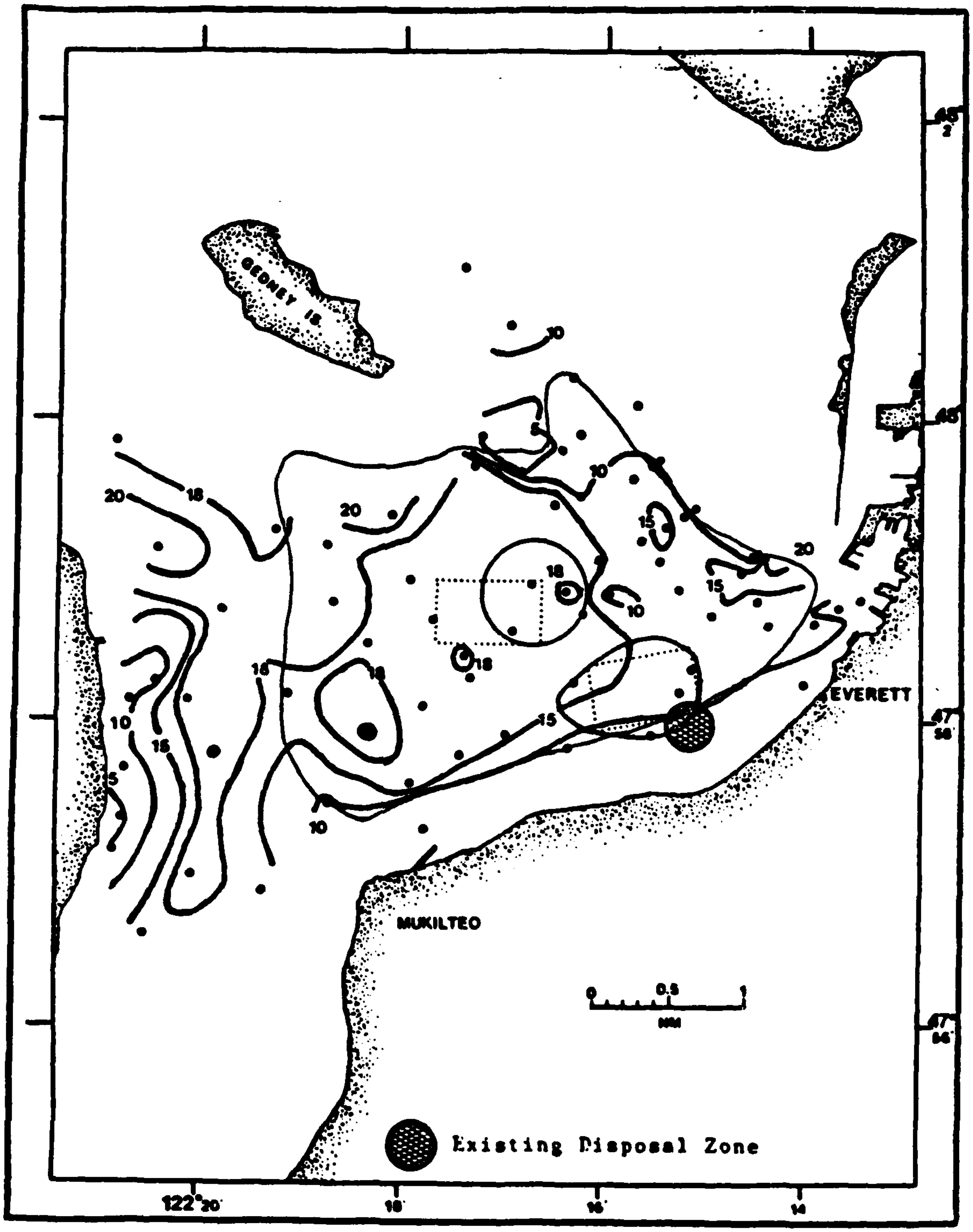


Figure II.10-13 Preferred and alternative disposal sites in Port Gardner on contours of percent clay.

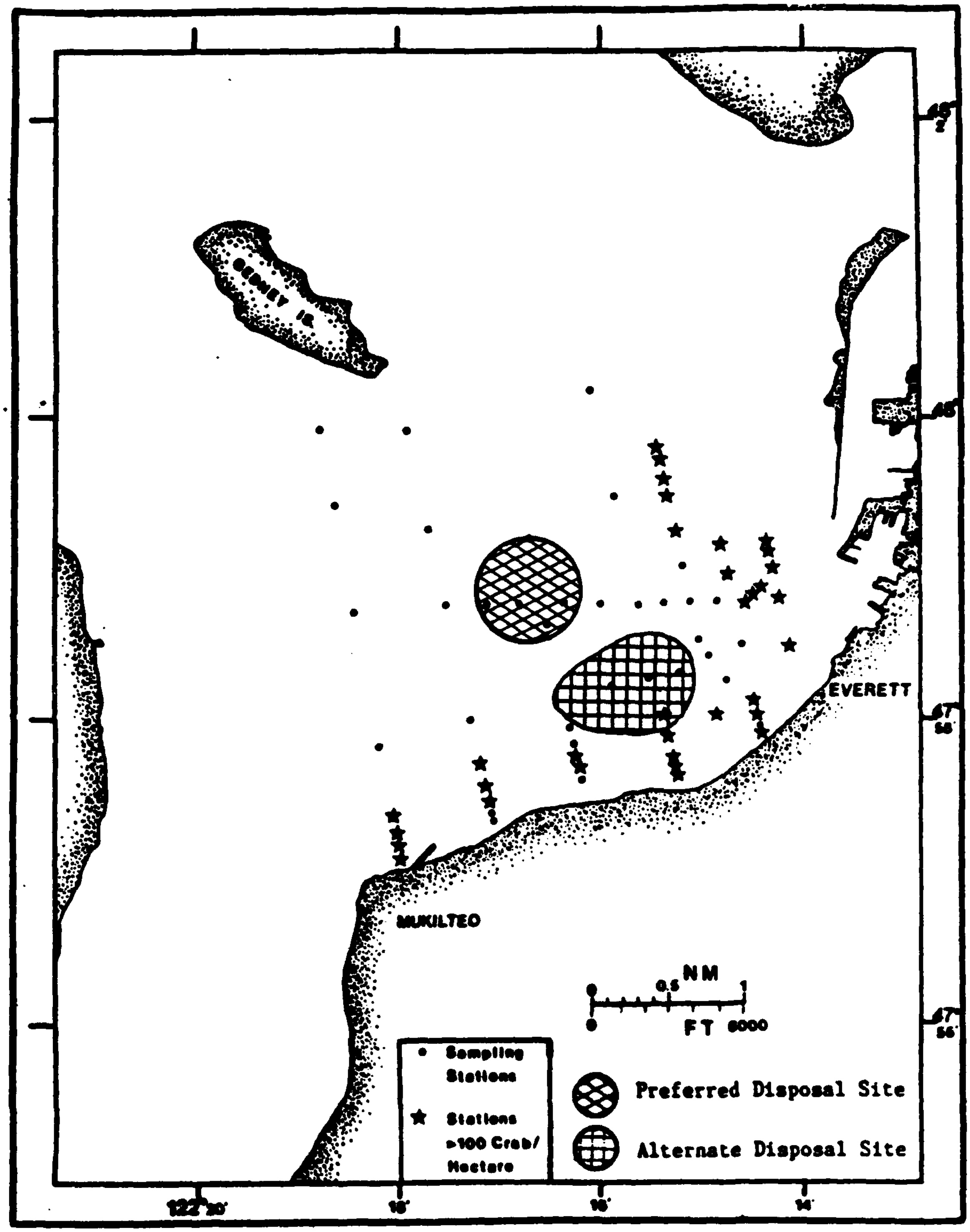


Figure II.10-14 Port Gardner combined crab distribution. Dots denote stations with crab populations below 100 per hectare and stars denote crab populations greater than 100 per hectare. (Source: adapted from Dinnel et al., 1986a-h)

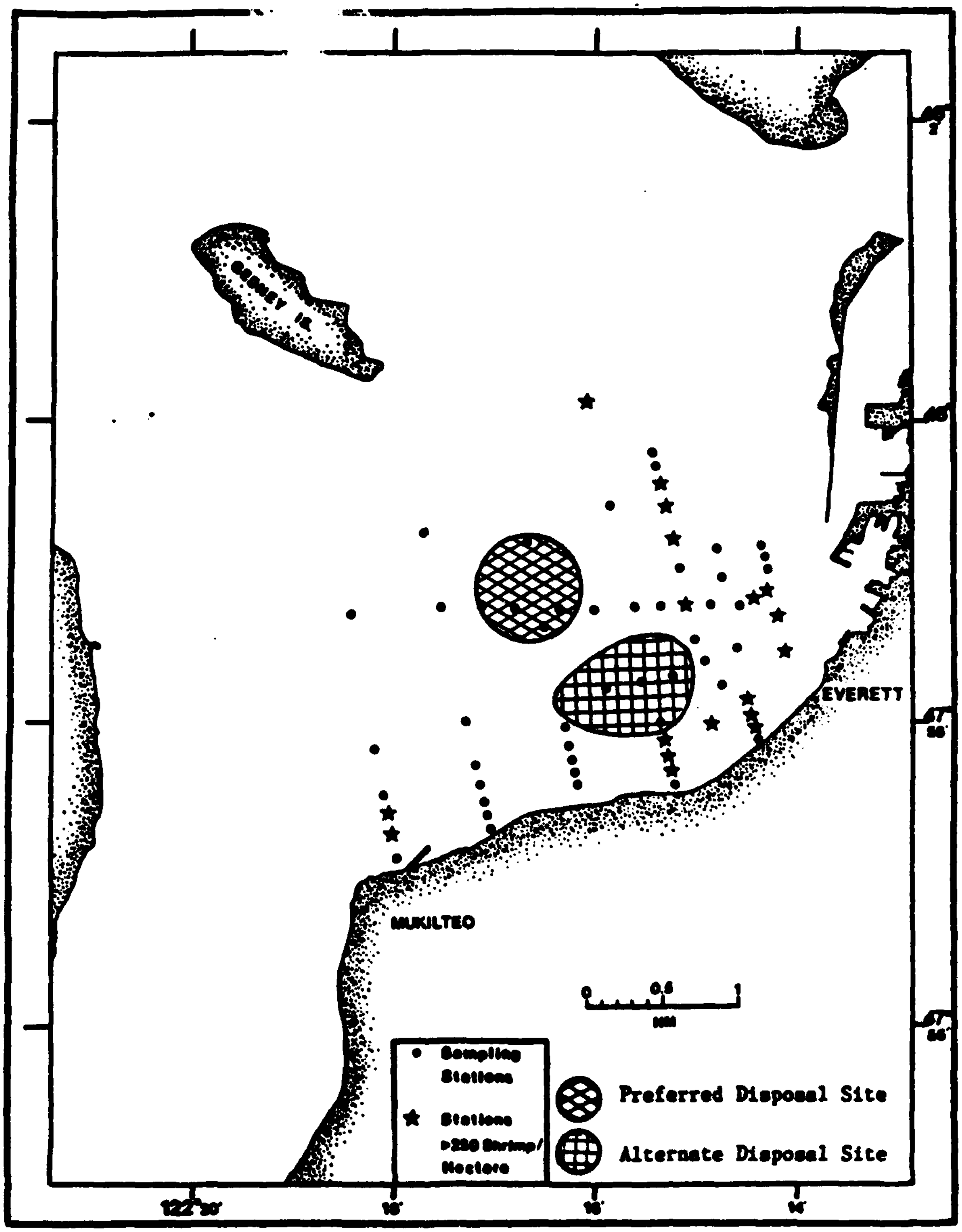


Figure II.10-15 Port Gardner combined shrimp distribution. Dots denote stations with shrimp populations below 250 per hectare and stars denote shrimp populations greater than 250 per hectare. (Source: adapted from Dinnel et al., 1986a-h)

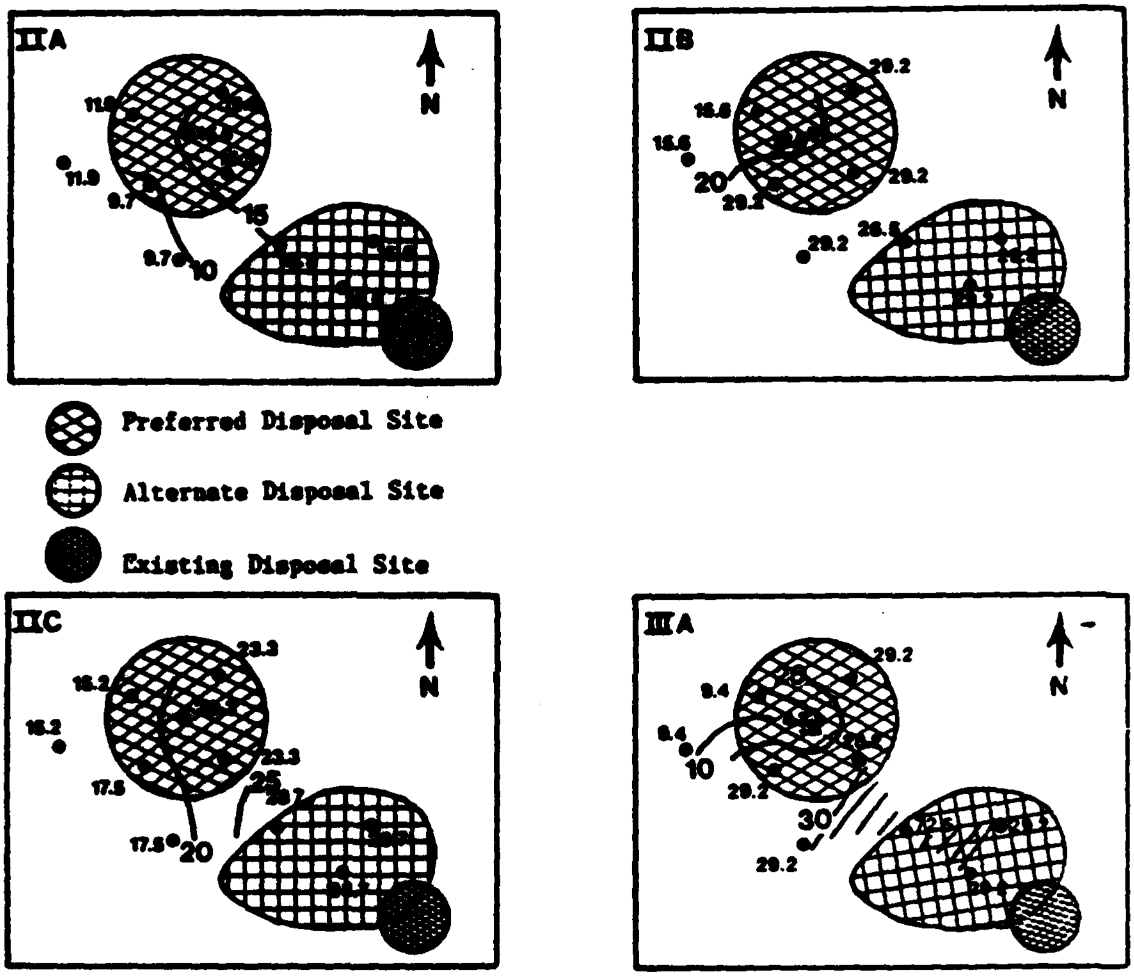


Figure II.10-16 Preferred and alternative disposal sites in Port Gardner on benthic biomass potentially available to four groups of fish (biomass in grams per square meter). (Source: adapted from Clarke, 1986)

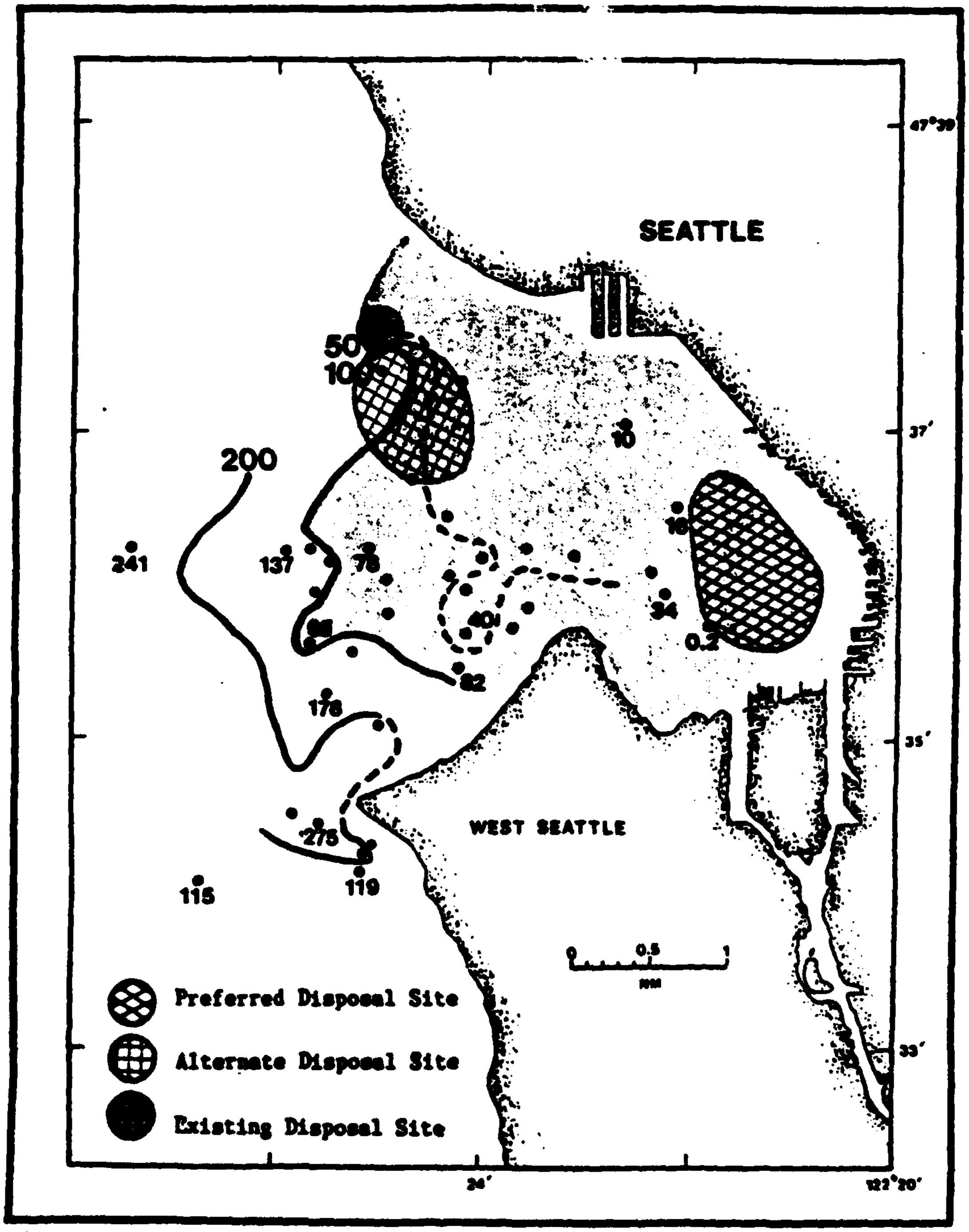


Figure II.10-17 Preferred and alternative disposal sites in Elliott Bay on contours of total variance ($cm^2 s^{-2}$) of the currents averaged over the water column.

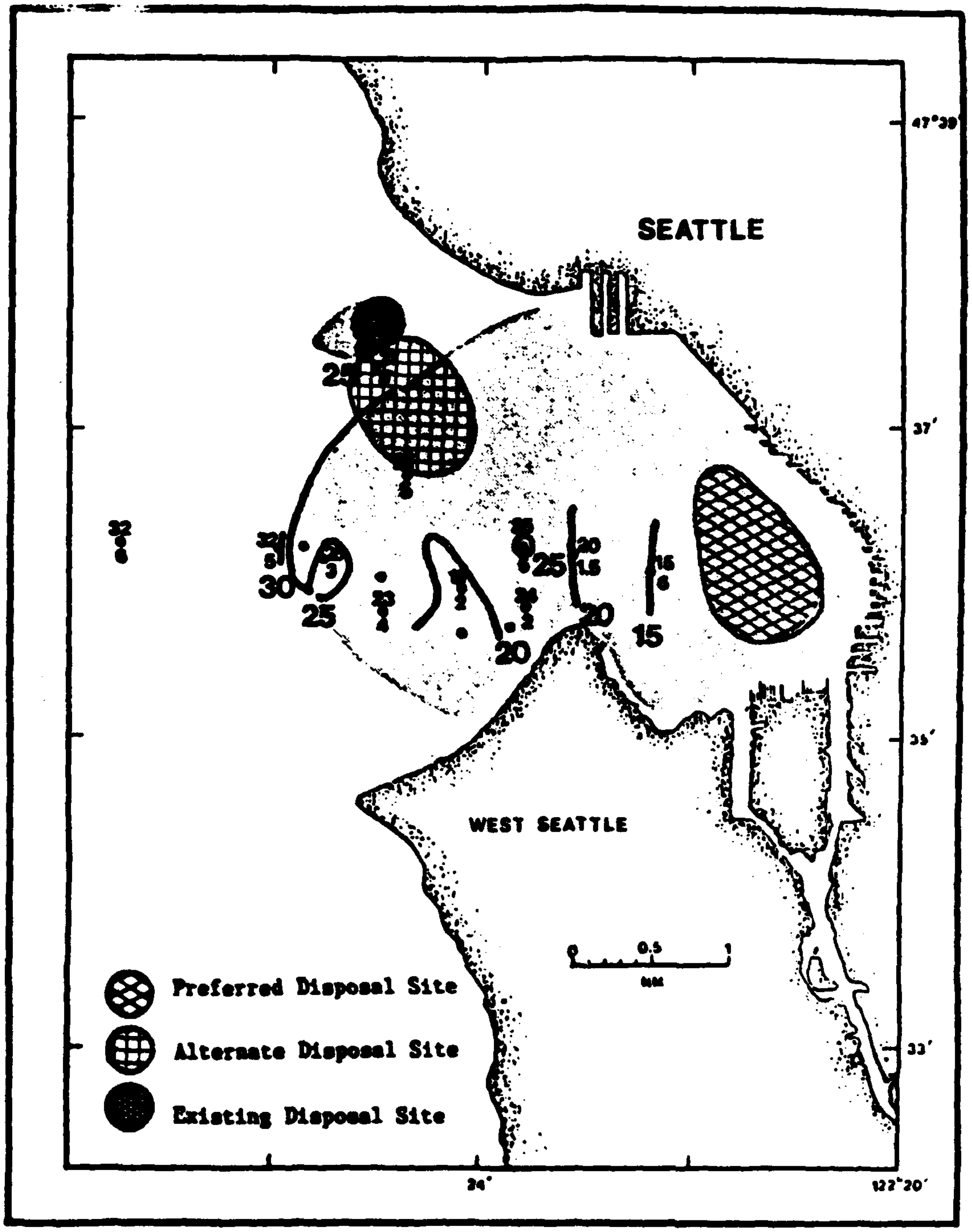


Figure II.10-18 Preferred and alternative disposal sites in Elliott Bay on contours of 1% fastest current speeds (cm/s) measured within 10 meters of the bottom.

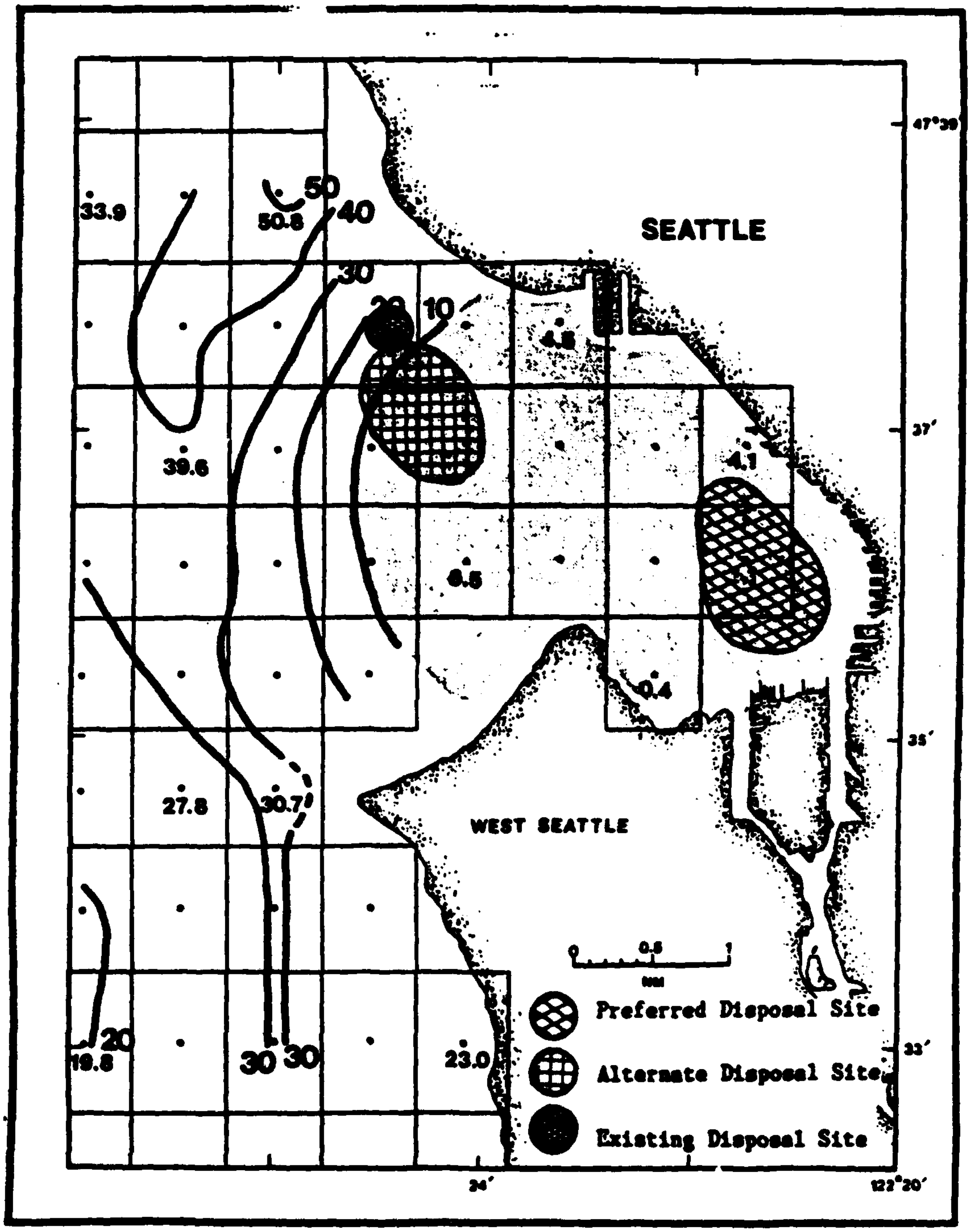


Figure II.10-19 Preferred and alternative disposal sites in Elliott Bay on contours of peak speeds (cm/s) for the extreme spring tide computed by the numerical tidal current model.

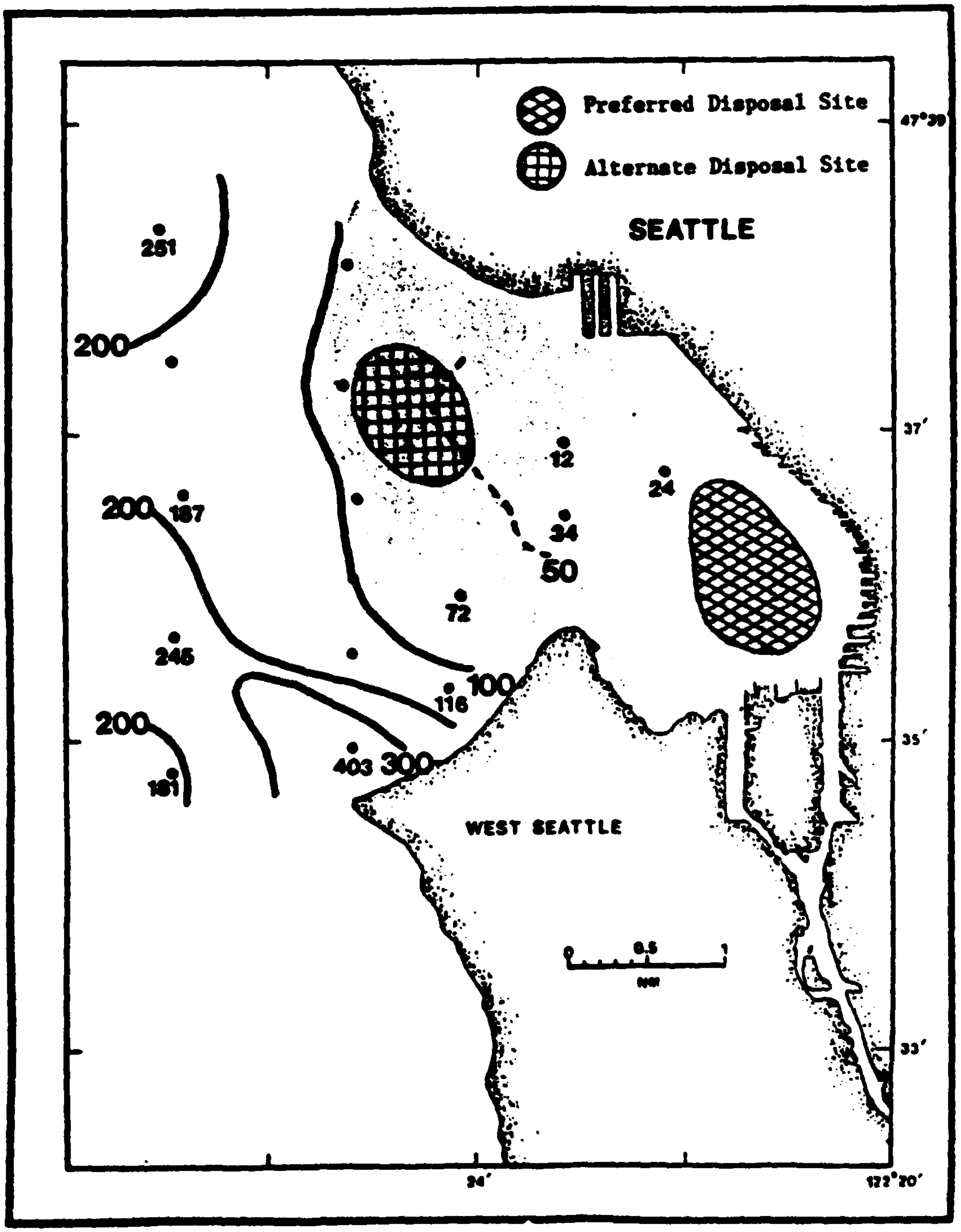
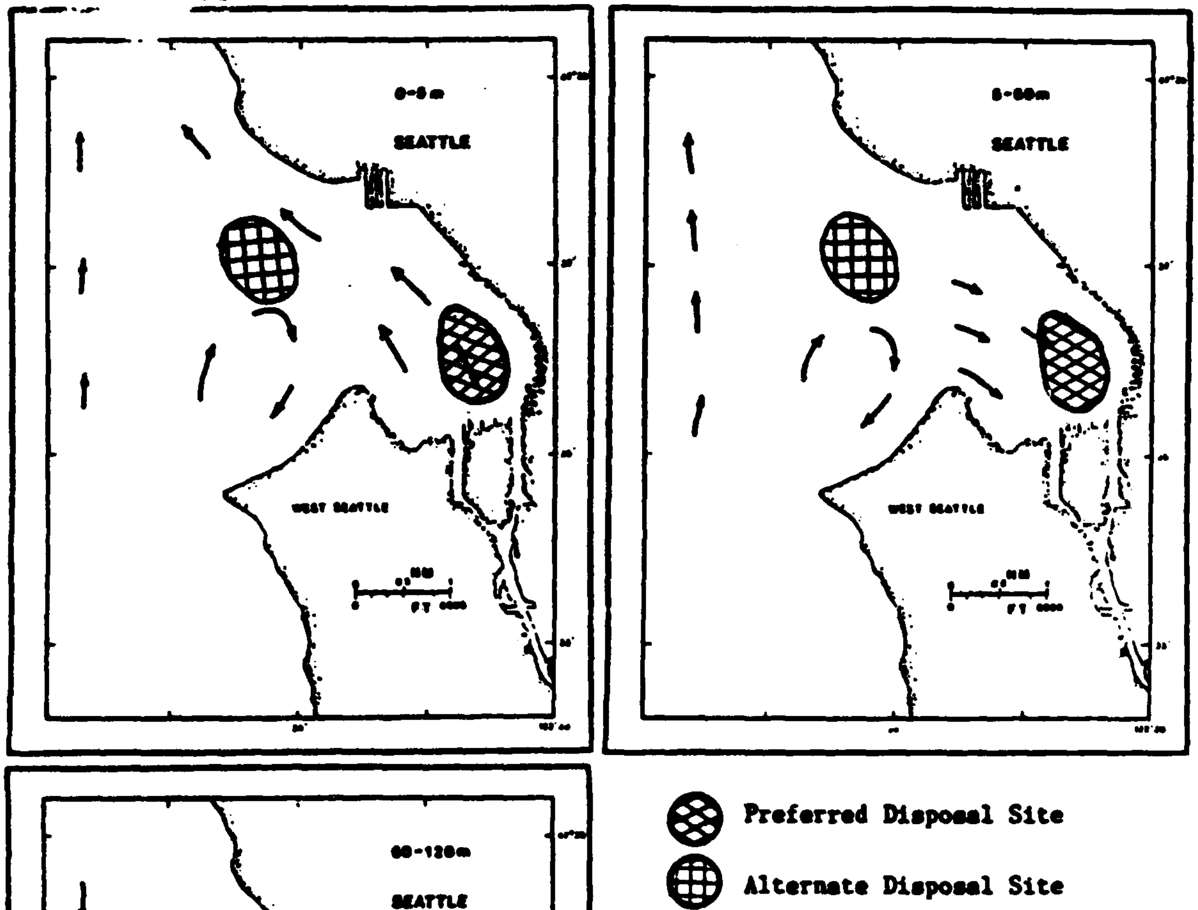
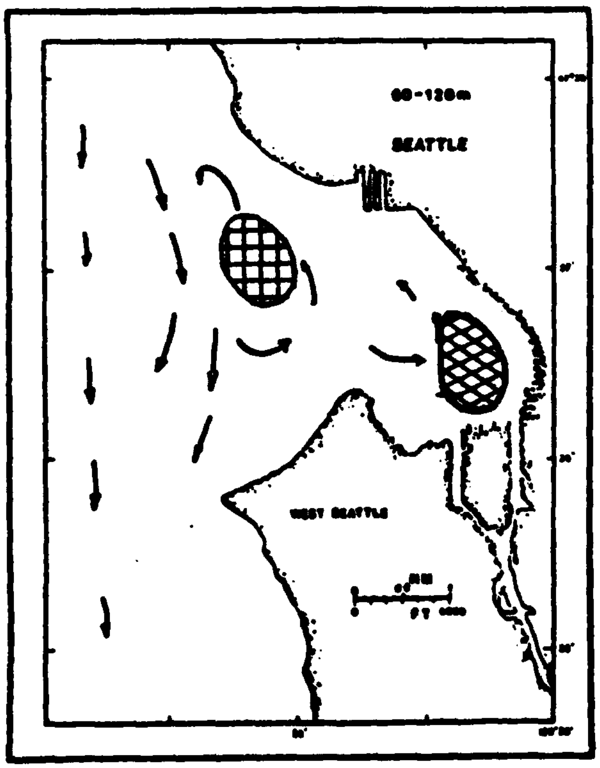


Figure II.10-20 Preferred and alternative disposal sites in Elliott Bay on contours of total variance (cm^2s^{-2}) of the currents at the surface of the hydraulic tidal model.





.Figure II.10-21

Estimated pattern of prevailing currents in Elliott Bay in three depth ranges: A) the shallow surface layer in the depth range of approximately 0-5 meters; B) the intermediate depth layer in the depth range of 5-60 meters; and C) the deep layer in the depth range of 60-170 meters. (Source: EHI)

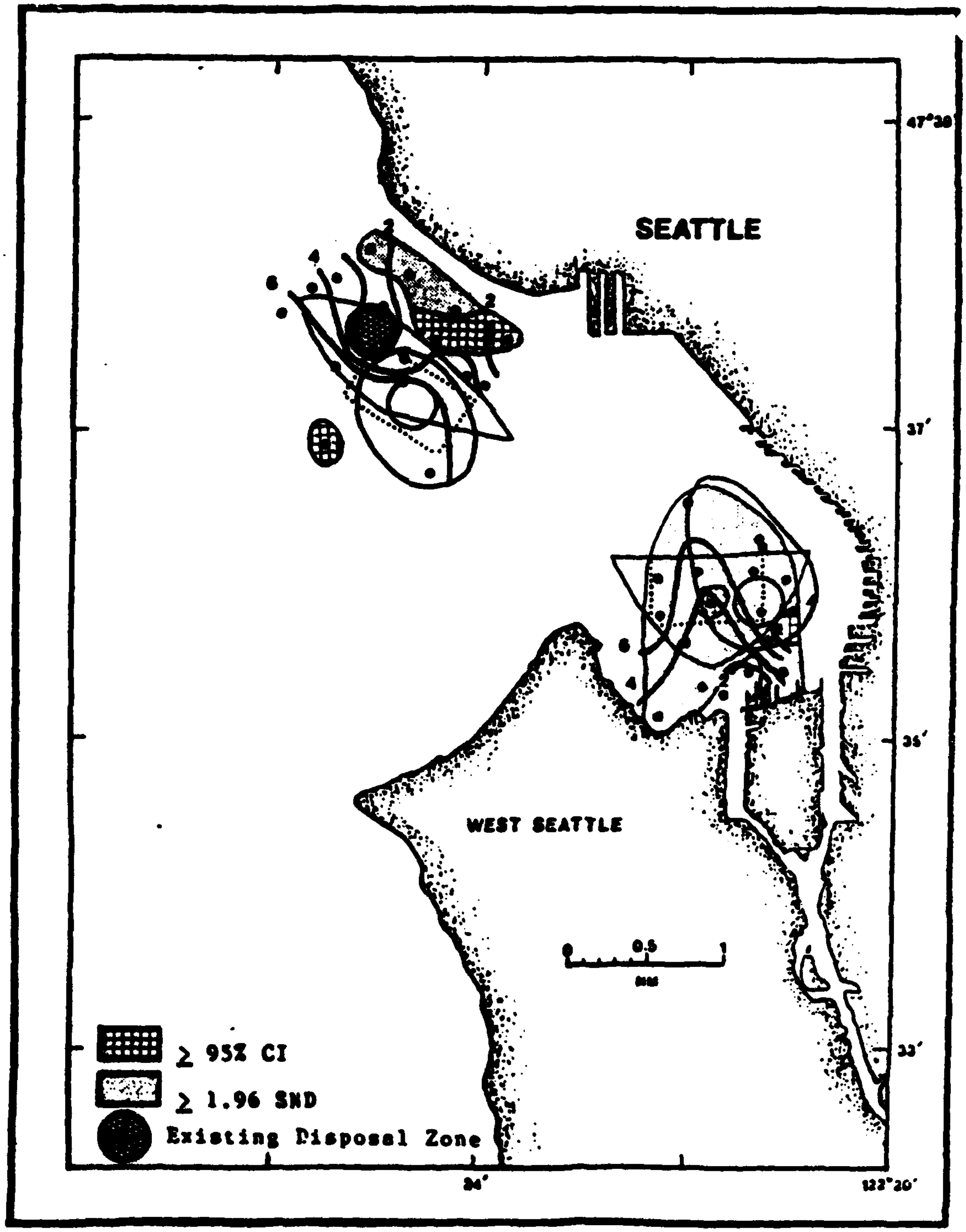


Figure II.10-22 Preferred and alternative disposal sites in Elliott Bay and the Fourmile Rock ZSF on contours of total volatile solids with areas exceeding the 95% CI and 1.96 SND.

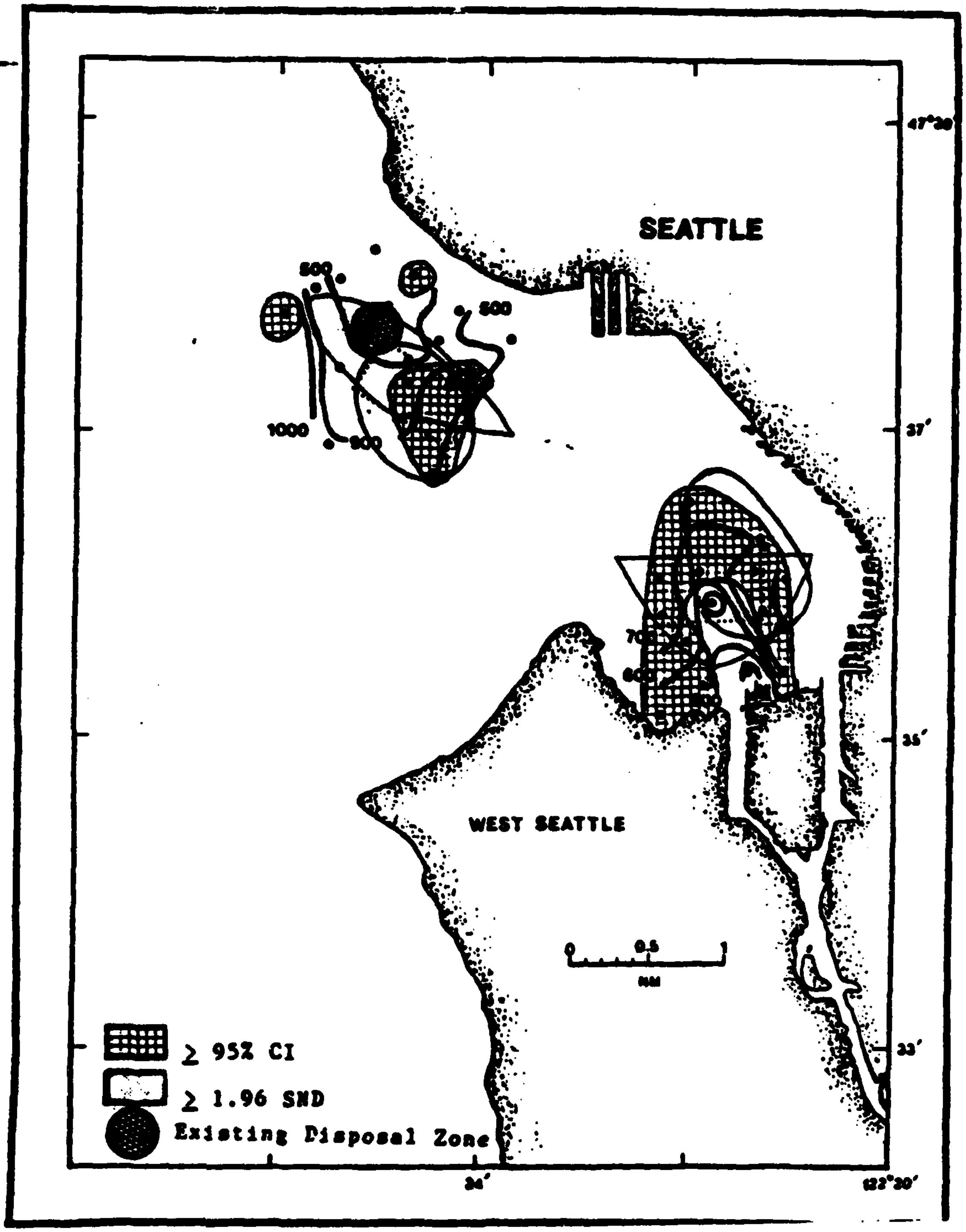


Figure II.10-23 Preferred and alternative disposal sites in Elliott Bay and the Fourmile Rock ZSF on contours of the BOD with areas exceeding the 95% CI and 1.96 SND.

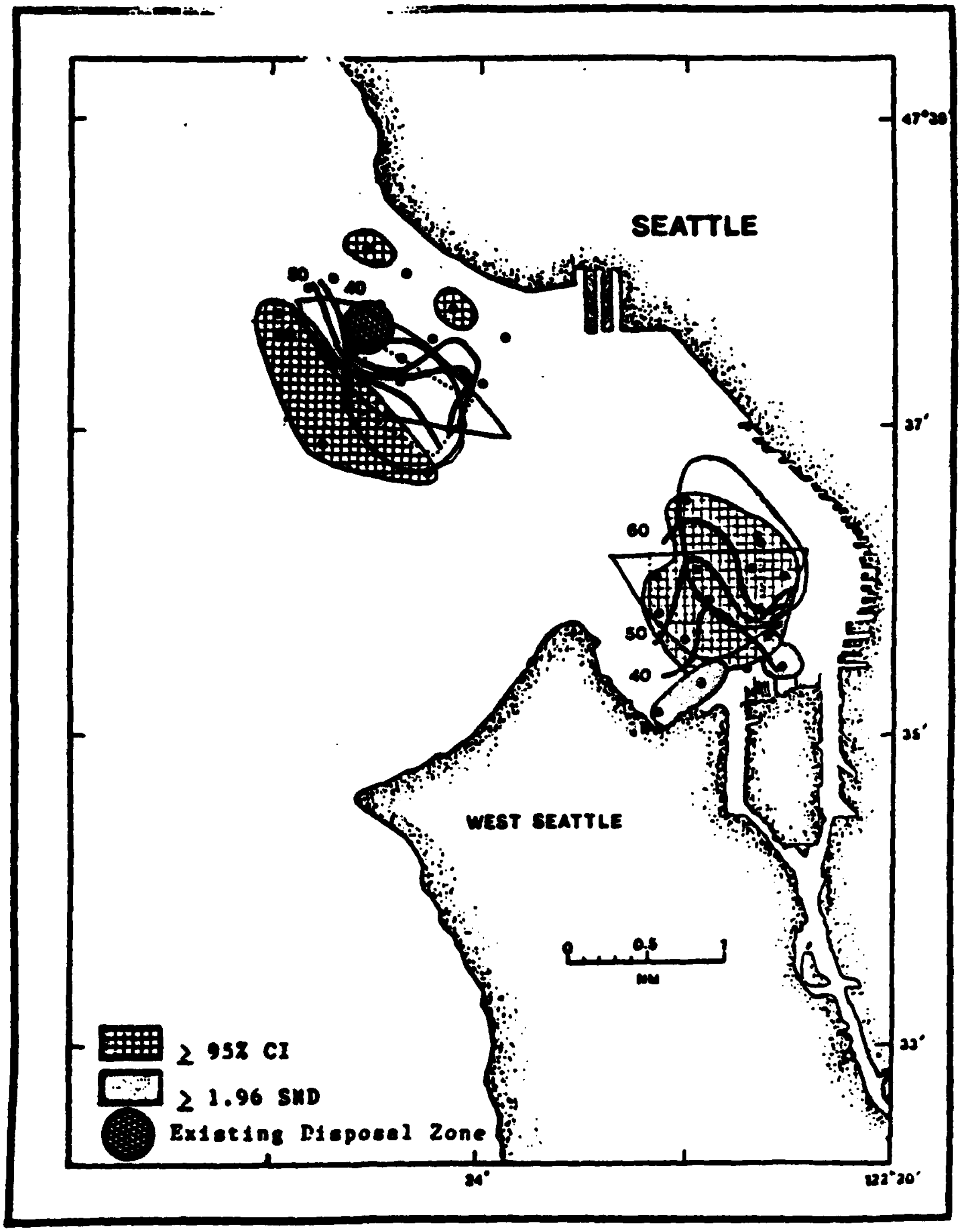


Figure II.10-24 Preferred and alternative disposal sites in Elliott Bay and the Fourmile Rock ZSF contours of percent water with areas exceeding the 95% CI and 1.96 SND.

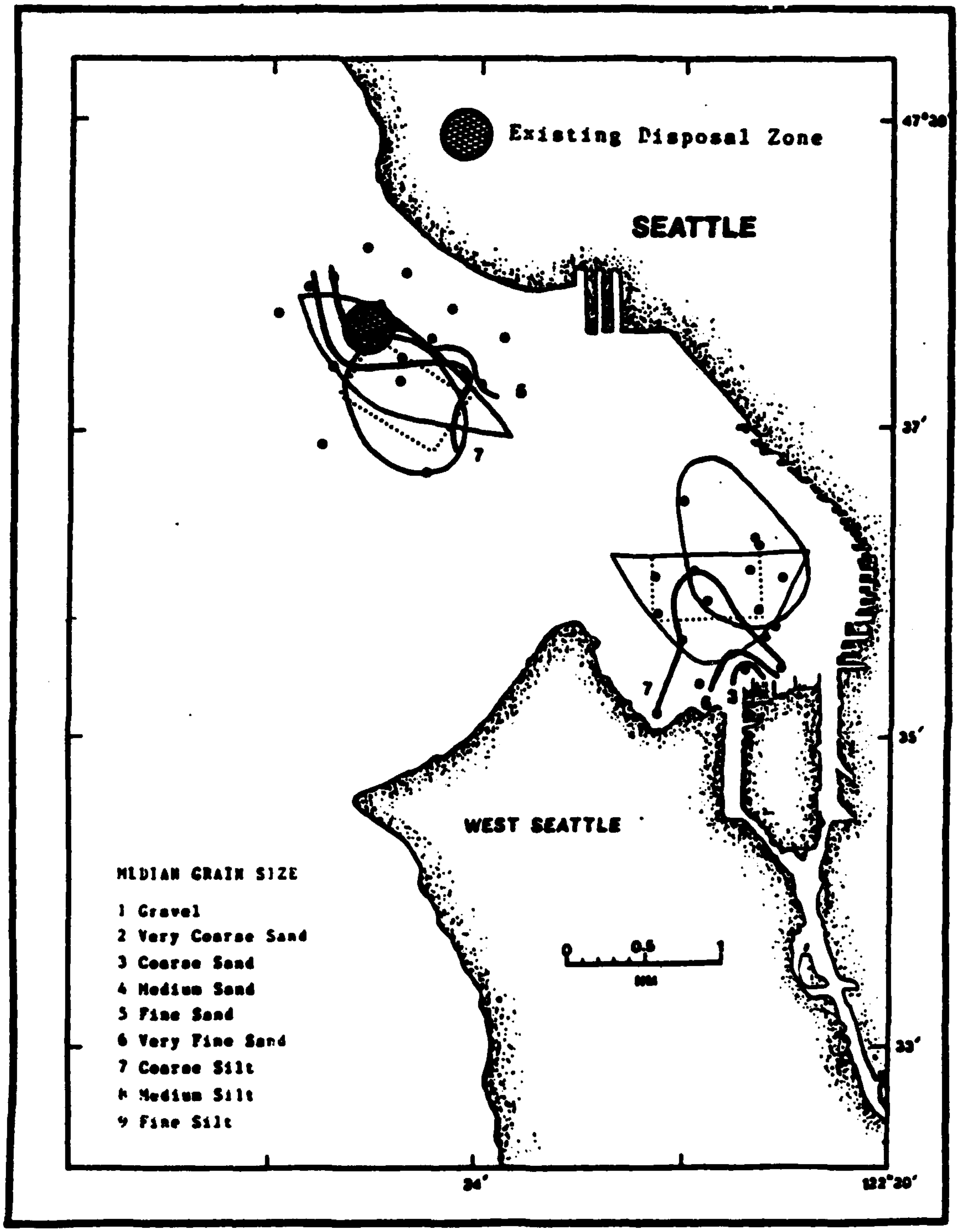


Figure II.10-25 Preferred and alternative disposal sites in Elliott Bay and the Fourmile Rock ZSF on contours of grain size.

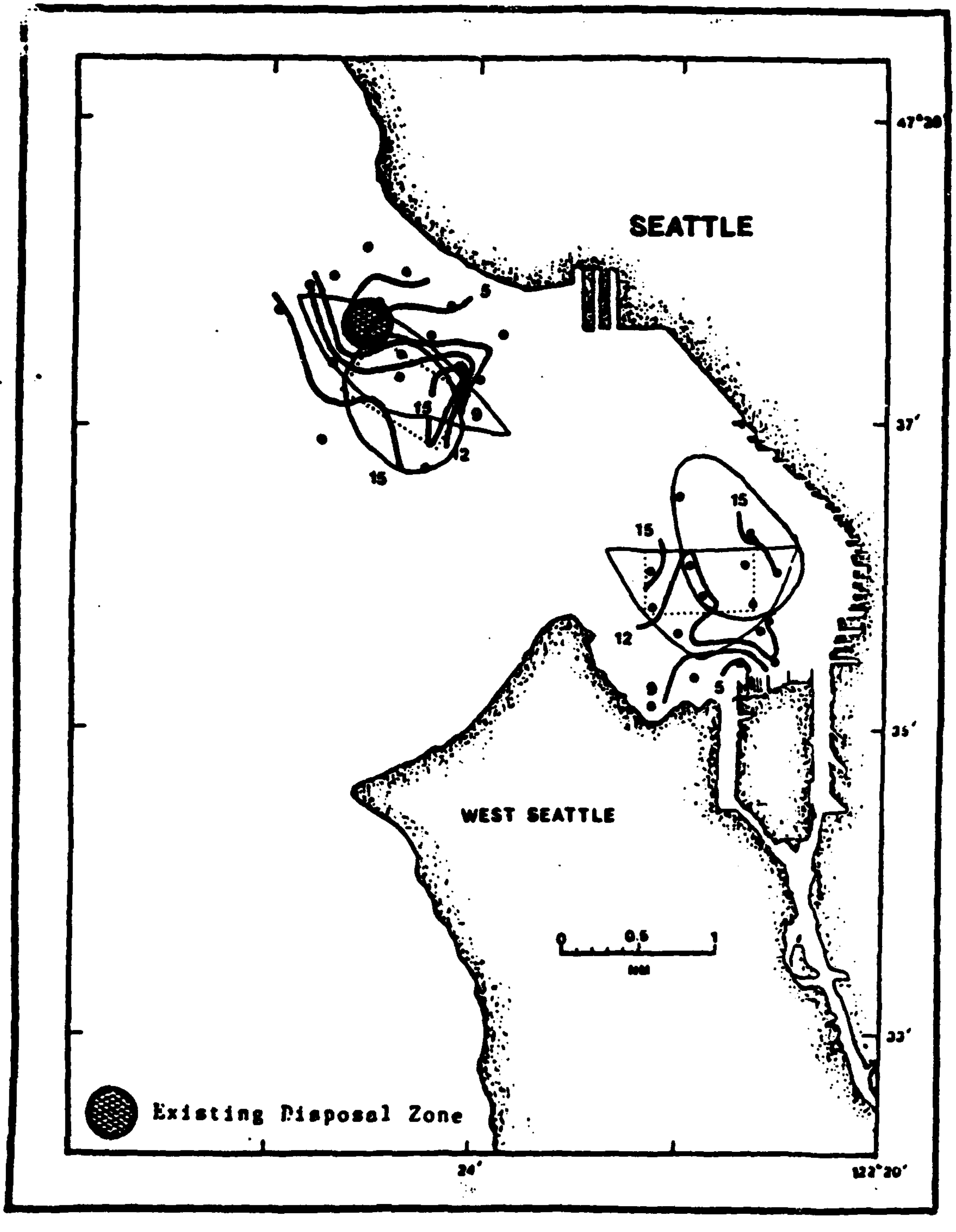


Figure II.10-26 Preferred and alternative disposal sites in Elliott Bay on contours of percent clay.

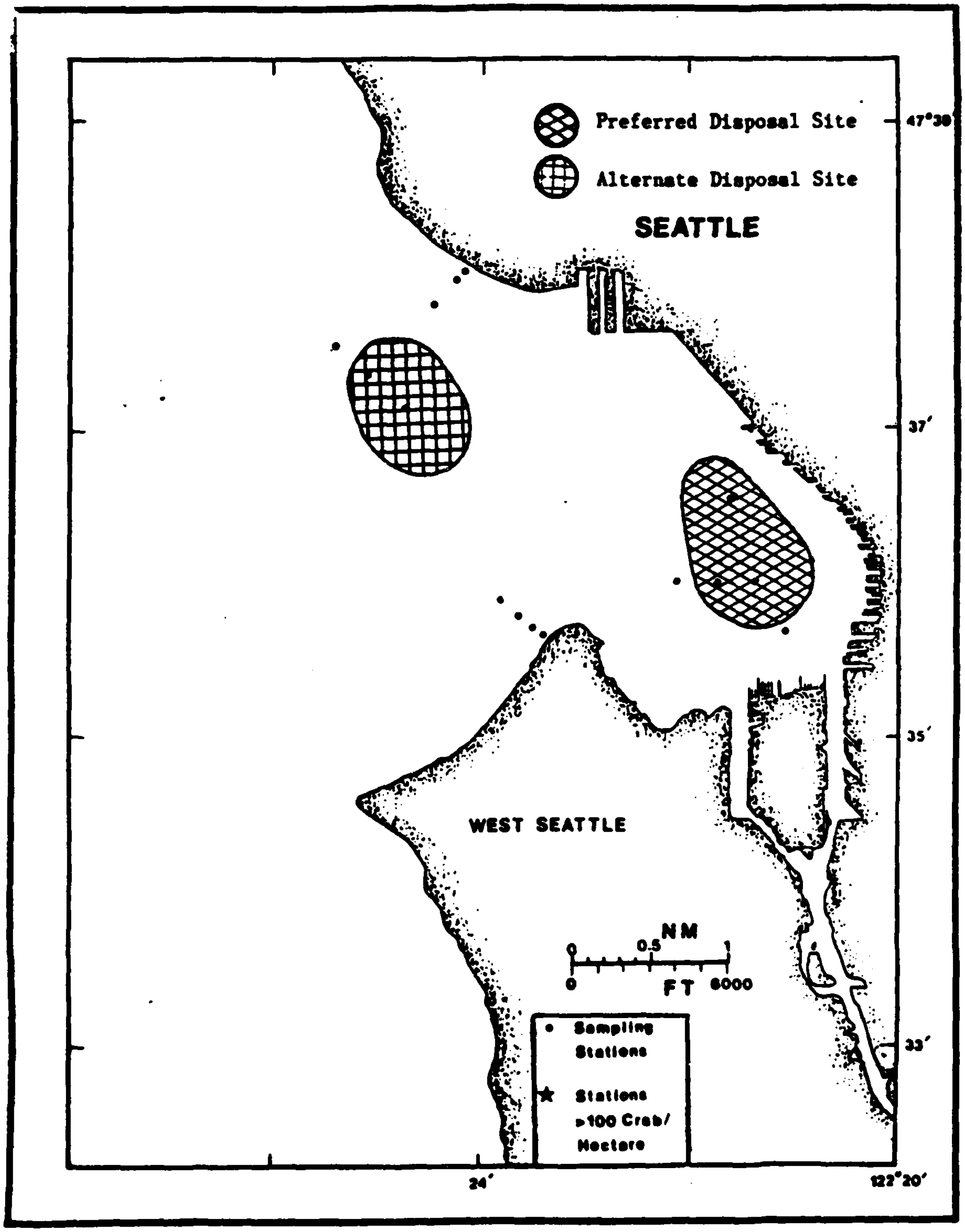


Figure II.10-27 Elliott Bay combined crab distribution. Dots denote stations with crab populations below 100 per hectare and stars denote crab populations greater than 100 per hectare. (Source: adapted from Dinnel et al., 1986a-h)

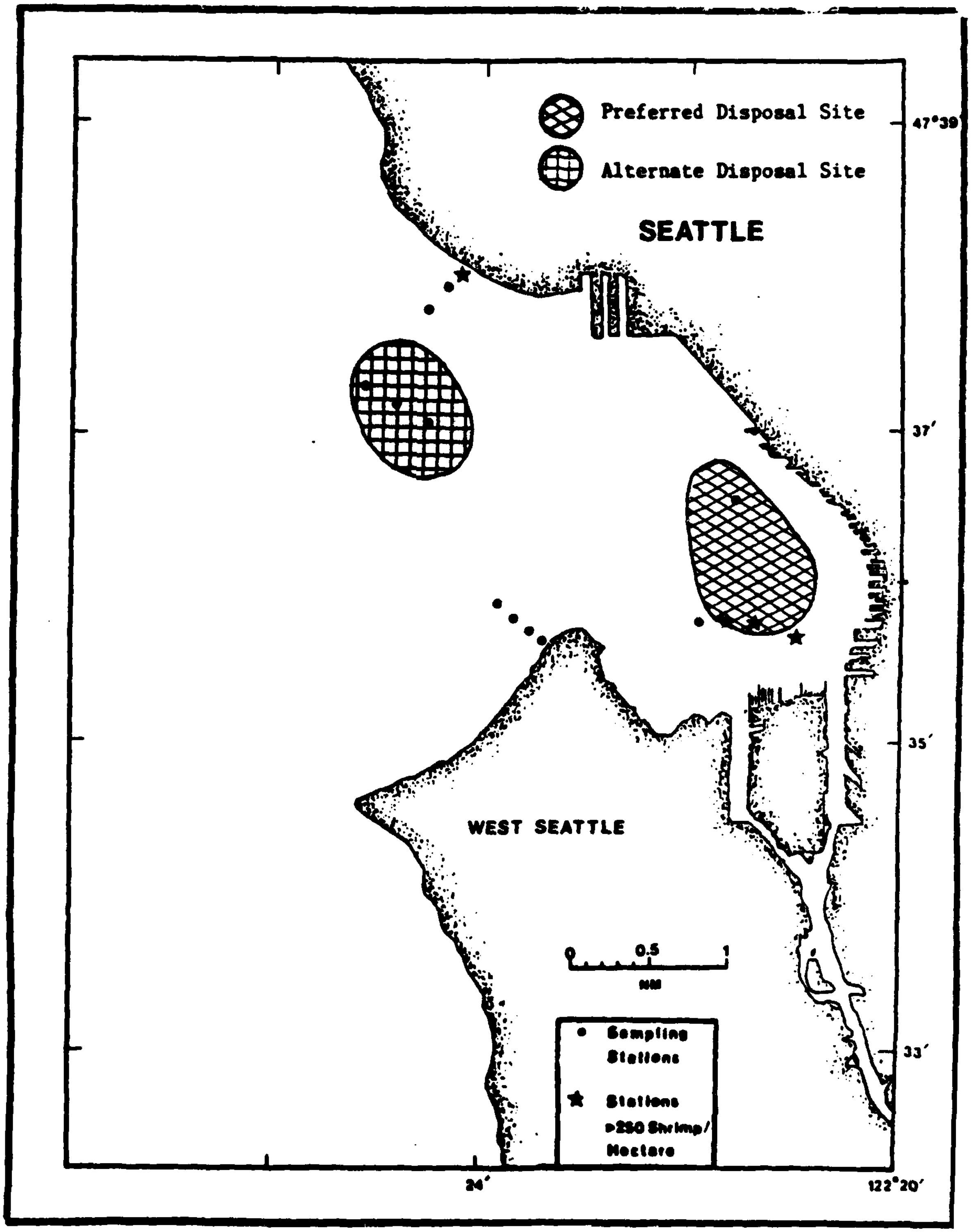


Figure II.10-28 Elliott Bay combined shrimp distribution. Dots denote stations with shrimp populations below 250 per hectare and stars denote shrimp populations greater than 250 per hectare. (Source: adapted from Dinnel et al., 1986a-h)

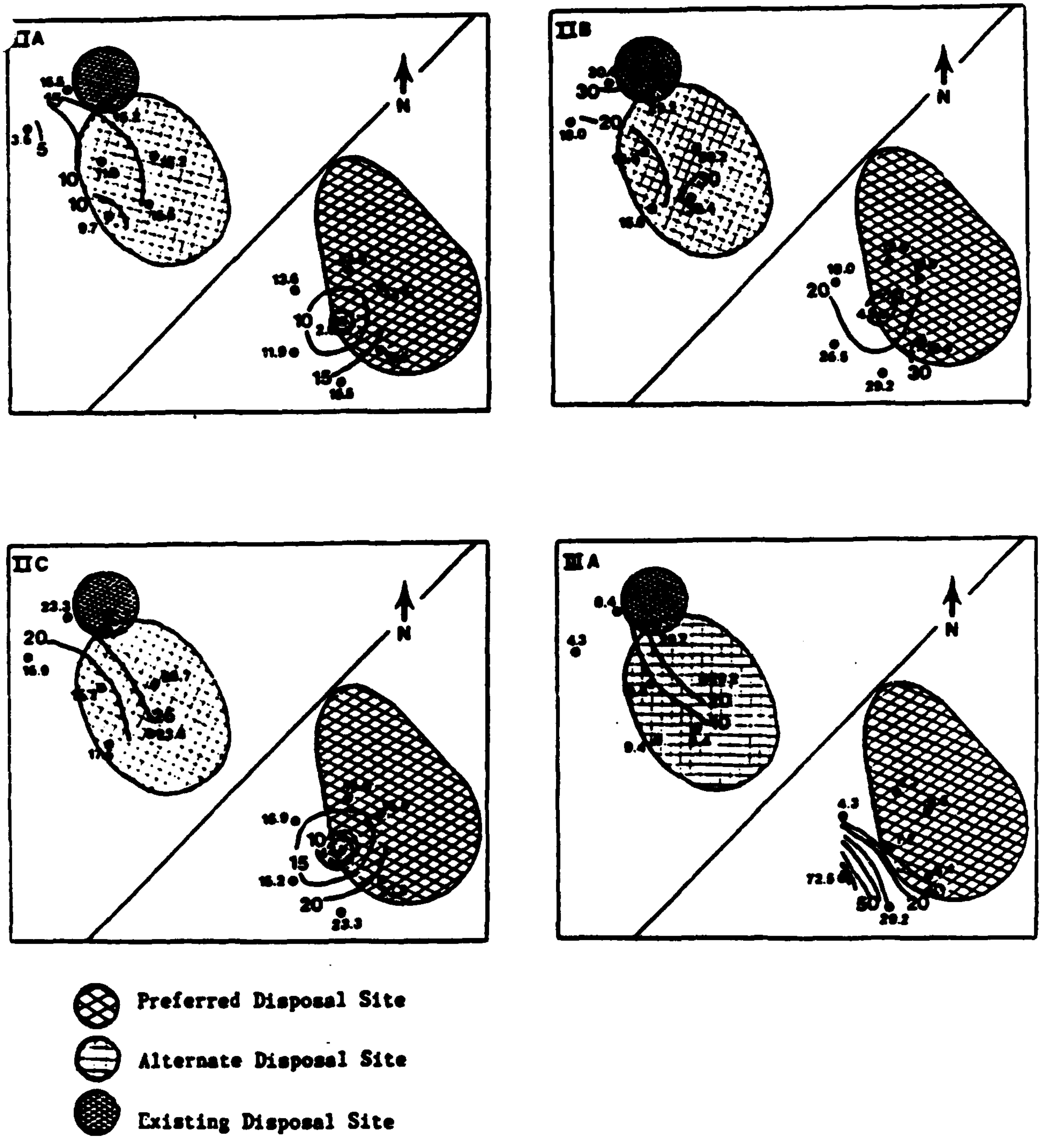


Figure II.10-29 Preferred and alternative disposal sites in Elliott Bay on benthic biomass potentially available to four groups of fish (biomass in grams per square meter). (Source: adapted from Clarke, 1986)

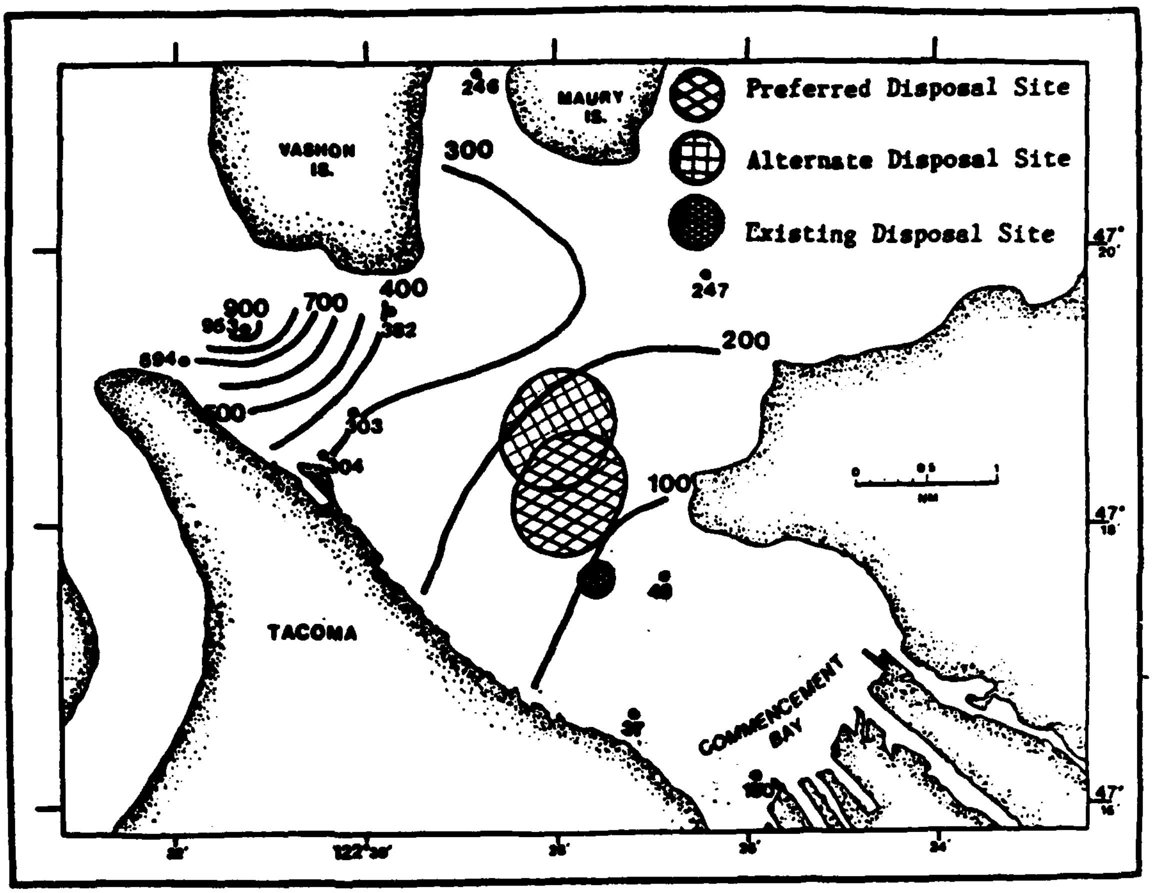


Figure II.10-30 Preferred and alternative disposal sites in Commencement Bay on contours of total variance (cm^2s^{-2}) of the currents averaged over the water column.

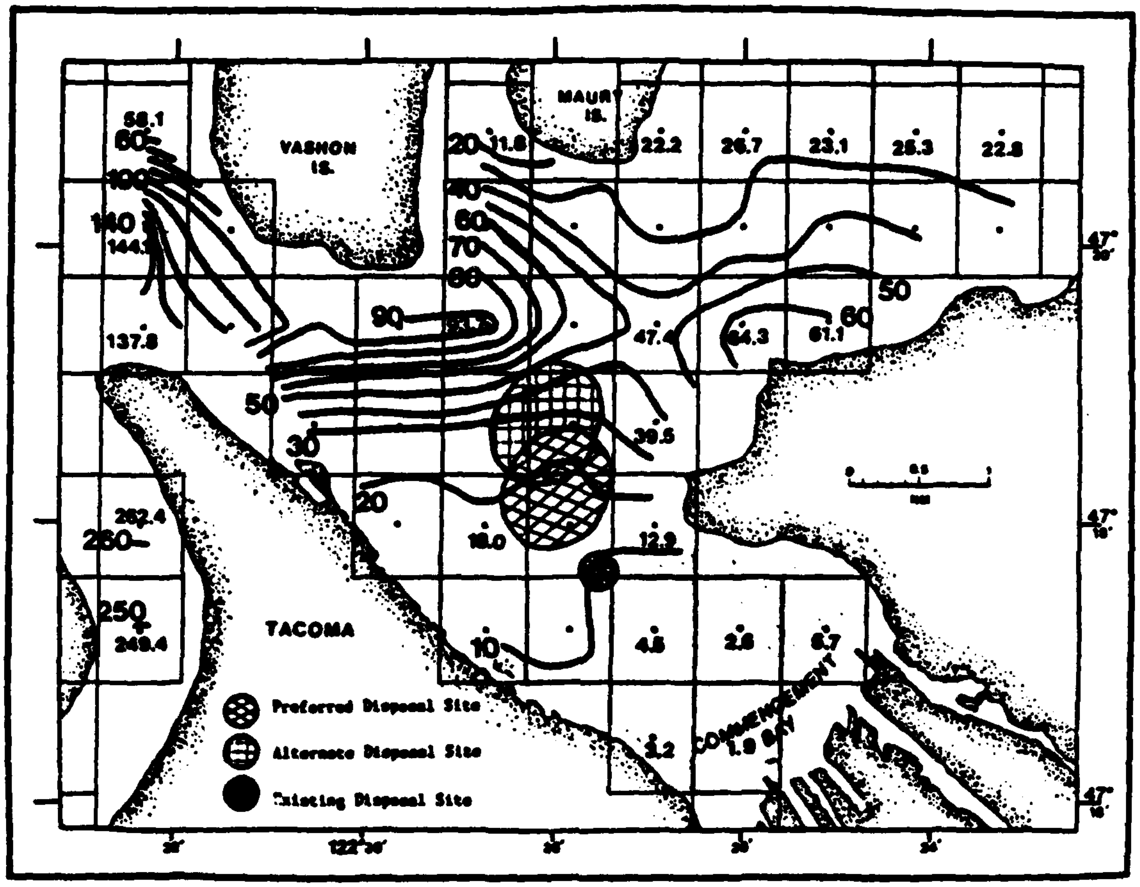


Figure II.10-31 Preferred and alternative disposal sites in Commencement Bay on contours of the peak speed (cm/s) computed by the numerical tidal model for the extreme spring tide.

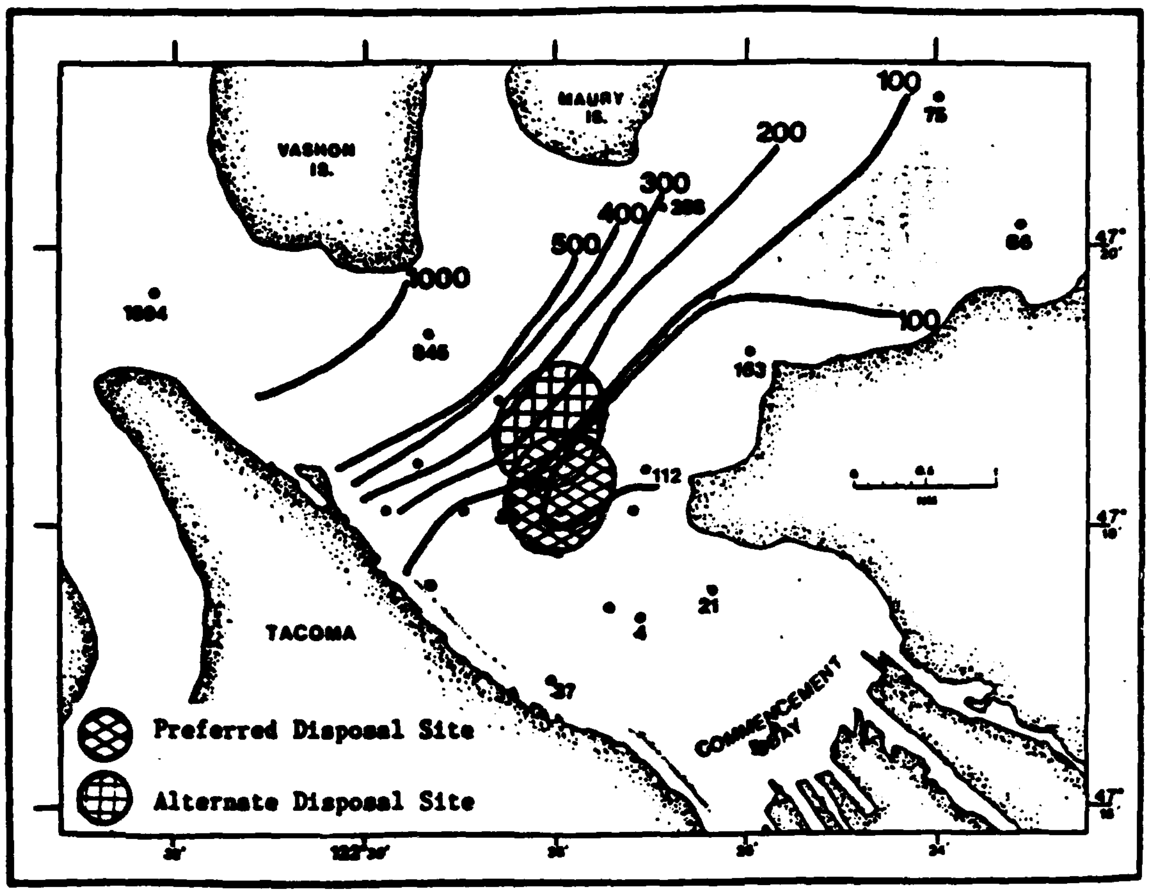


Figure II.10-32 Preferred and alternative disposal sites in Commencement Bay on contours of total variance (cm^2s^{-2}) of the currents computed at the water surface in the hydraulic model.

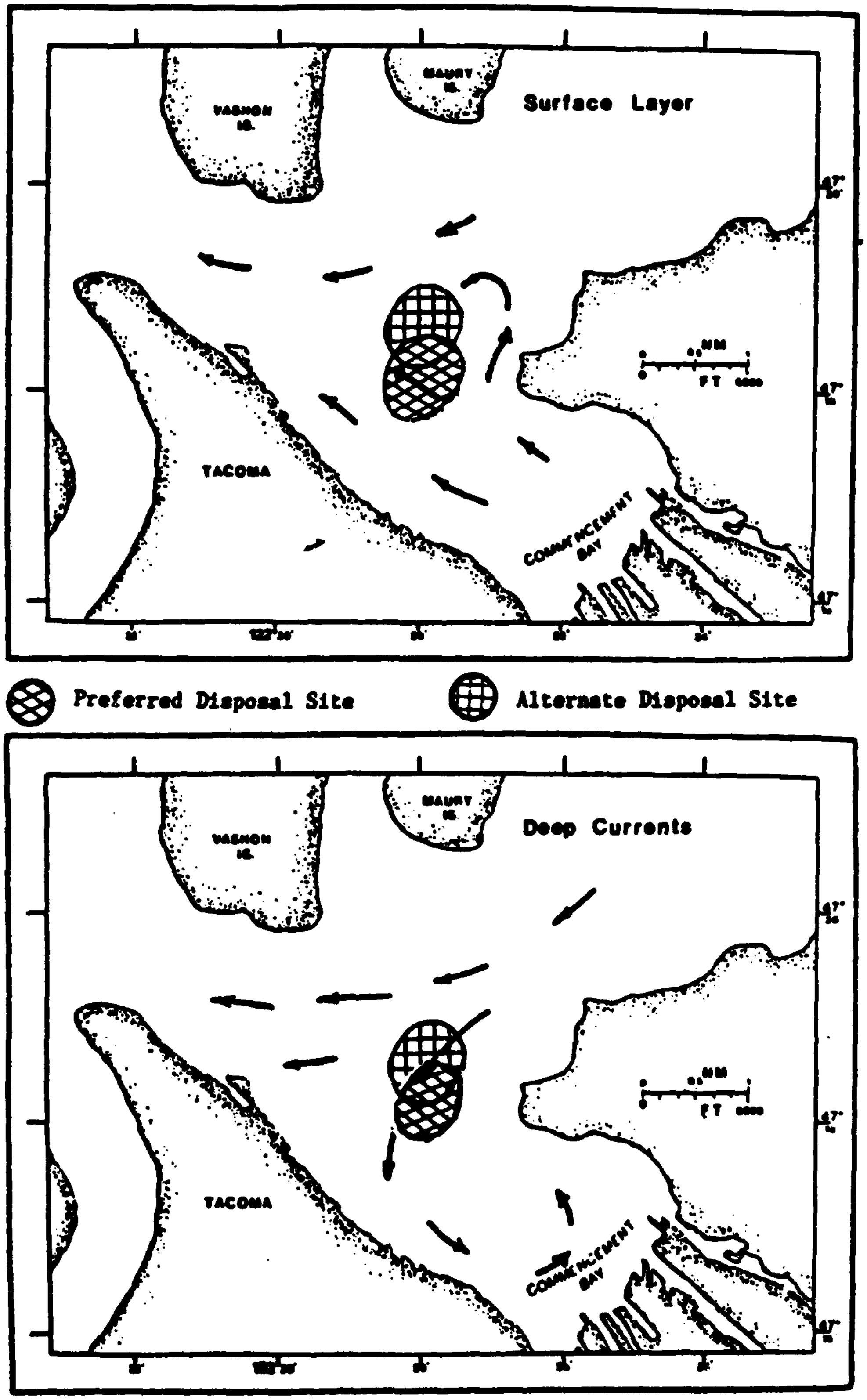


Figure II.10-33 Estimated pattern of prevailing currents in Commencement Bay in the shallow surface layer (upper panel), and in the deeper layer (lower panel). (Source: EHI)

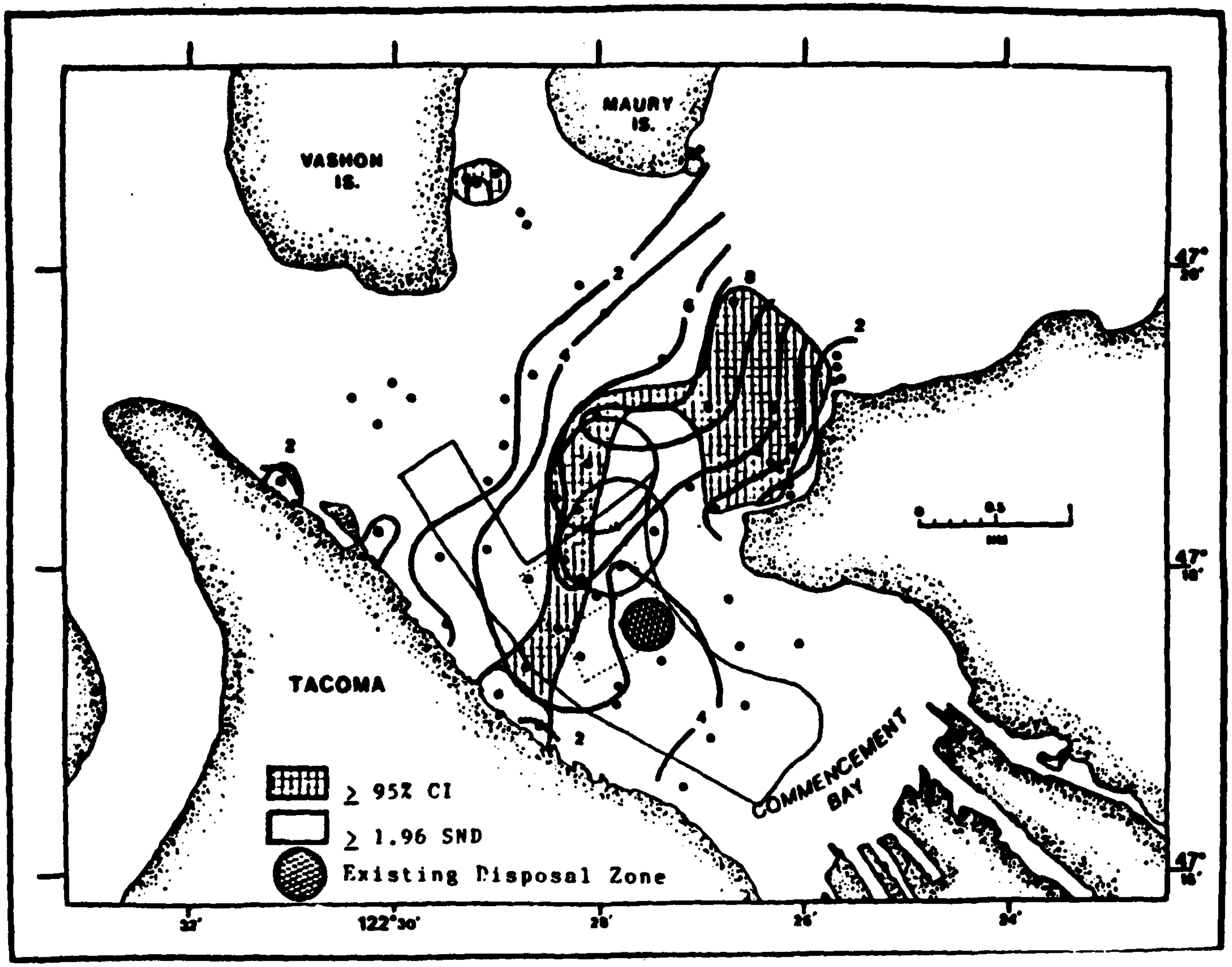


Figure II.10-34 Preferred and alternative disposal sites in Commencement Bay on contours of total volatile solids with areas exceeding 95% CI and 1.96 SND.

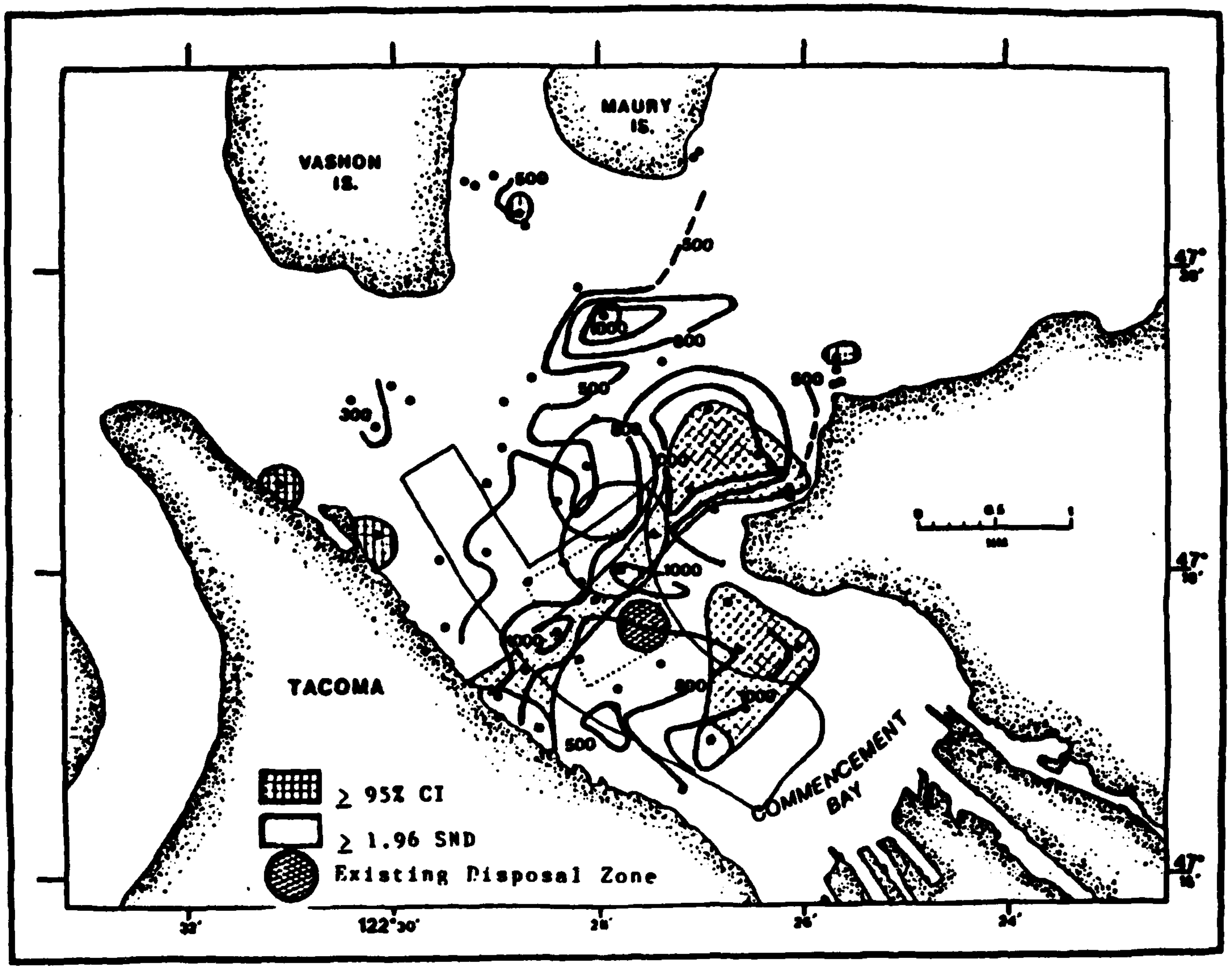


Figure II.10-35 Preferred and alternative disposal sites in Commencement Bay on contours of BOD with areas exceeding the 95% CI and 1.96 SND.

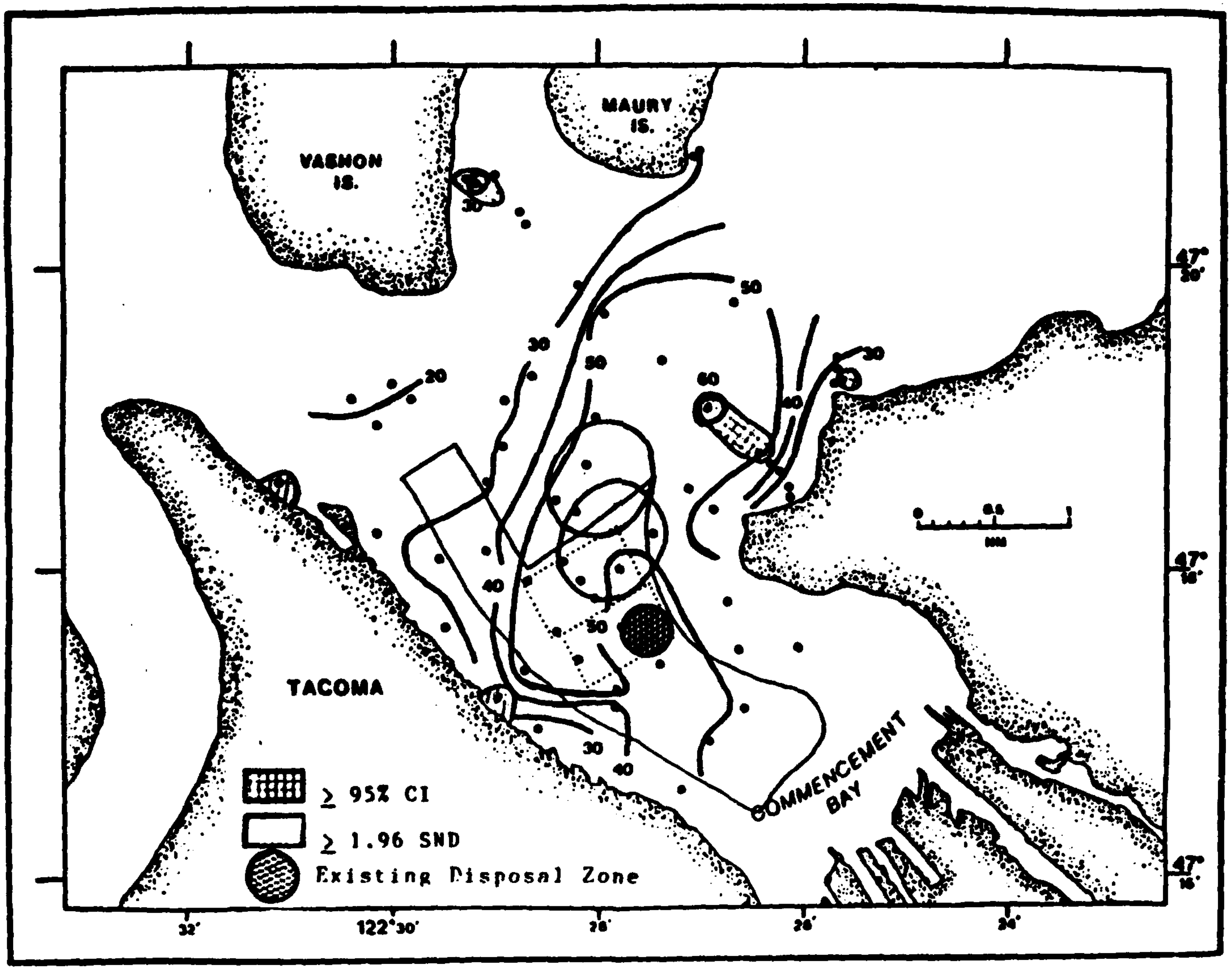


Figure II.10-36 Preferred and alternative disposal sites in Commencement Bay on contours of percent water with areas exceeding the 95 CI and 1.96 SND.

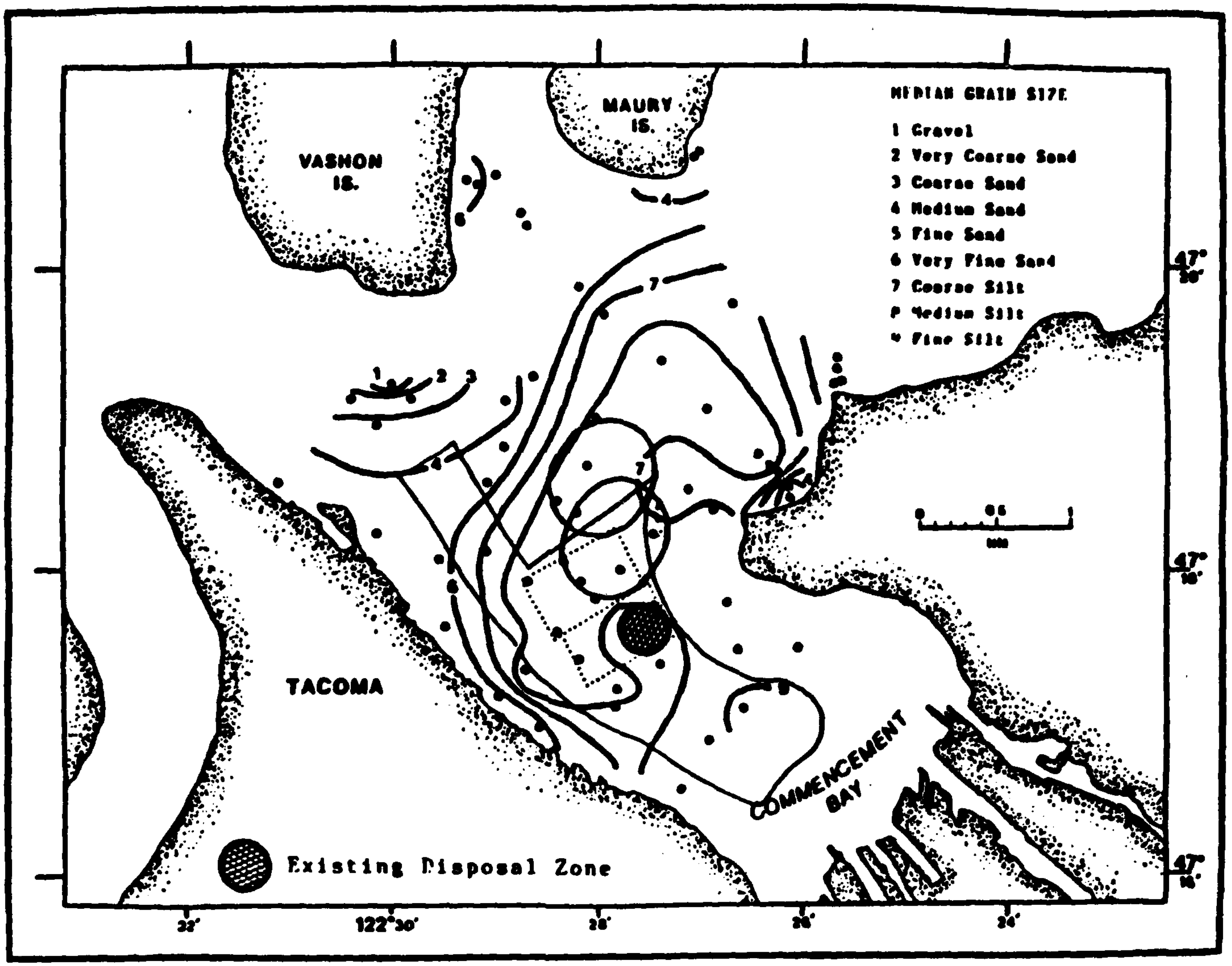


Figure II.10-37 Preferred and alternative disposal sites in Commencement Bay on contours of grain size.

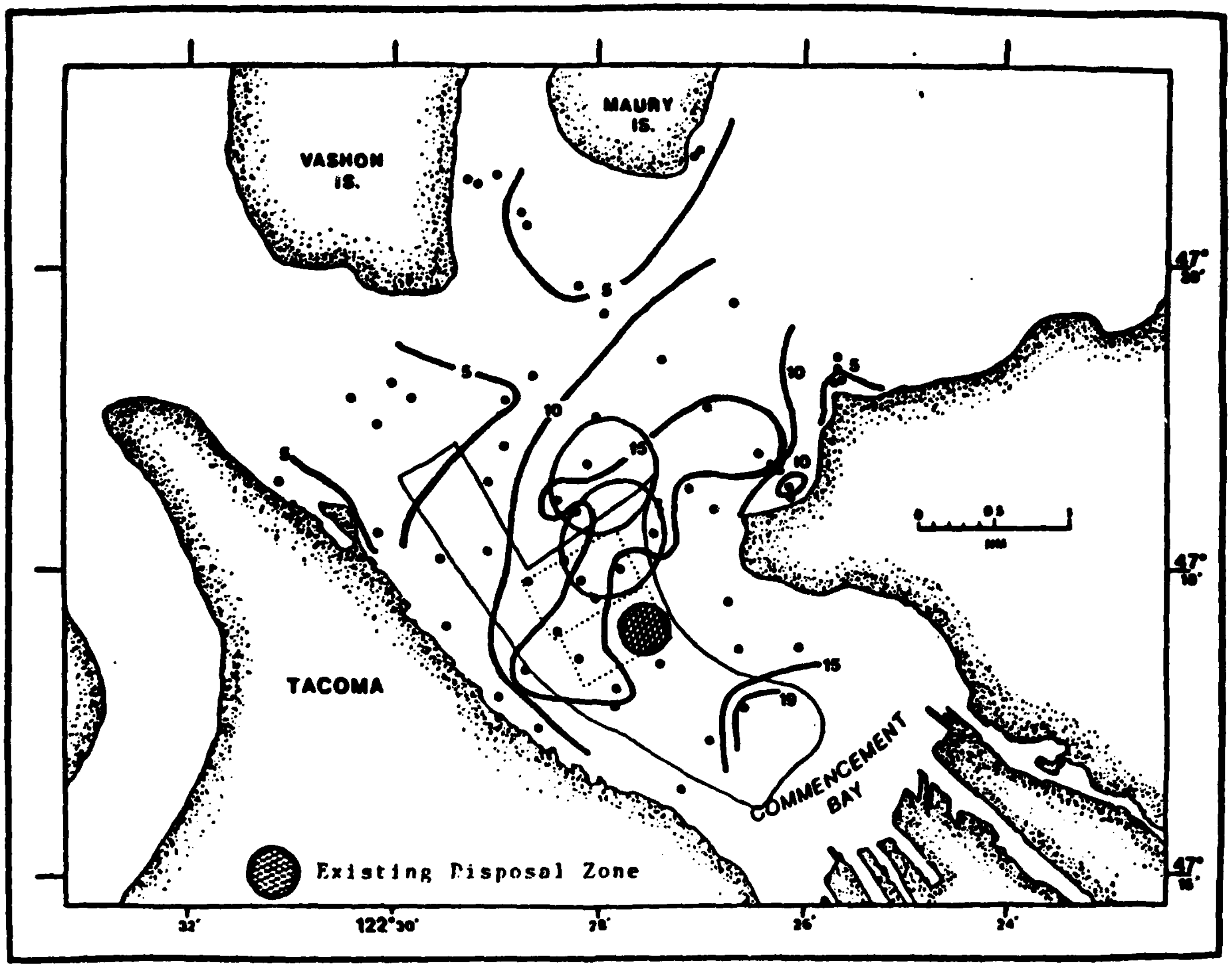


Figure II.10-38 Preferred and alternative disposal sites in Commencement Bay on contours of percent clay.

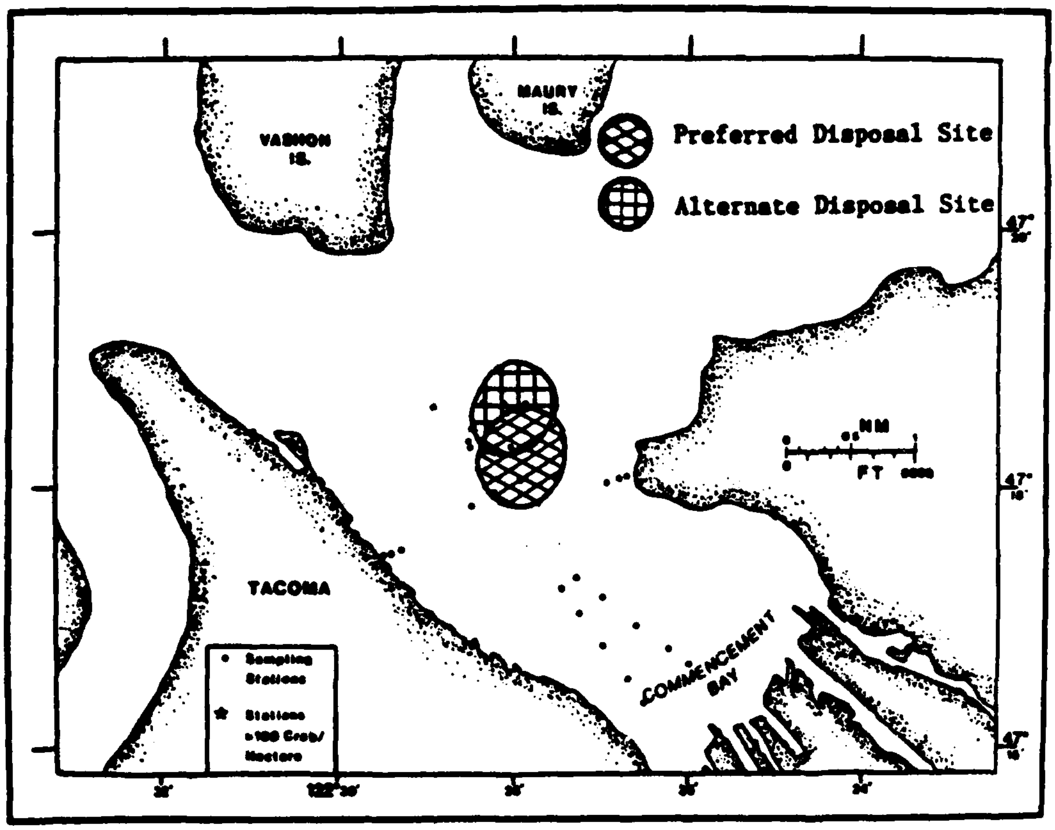


Figure II.10-39 Commencement Bay combined crab distribution. Dots denote stations with crab populations below 100 per hectare and stars denote crab populations greater than 100 per hectare. (Source: adapted from Dinnel et al., 1986a-h)

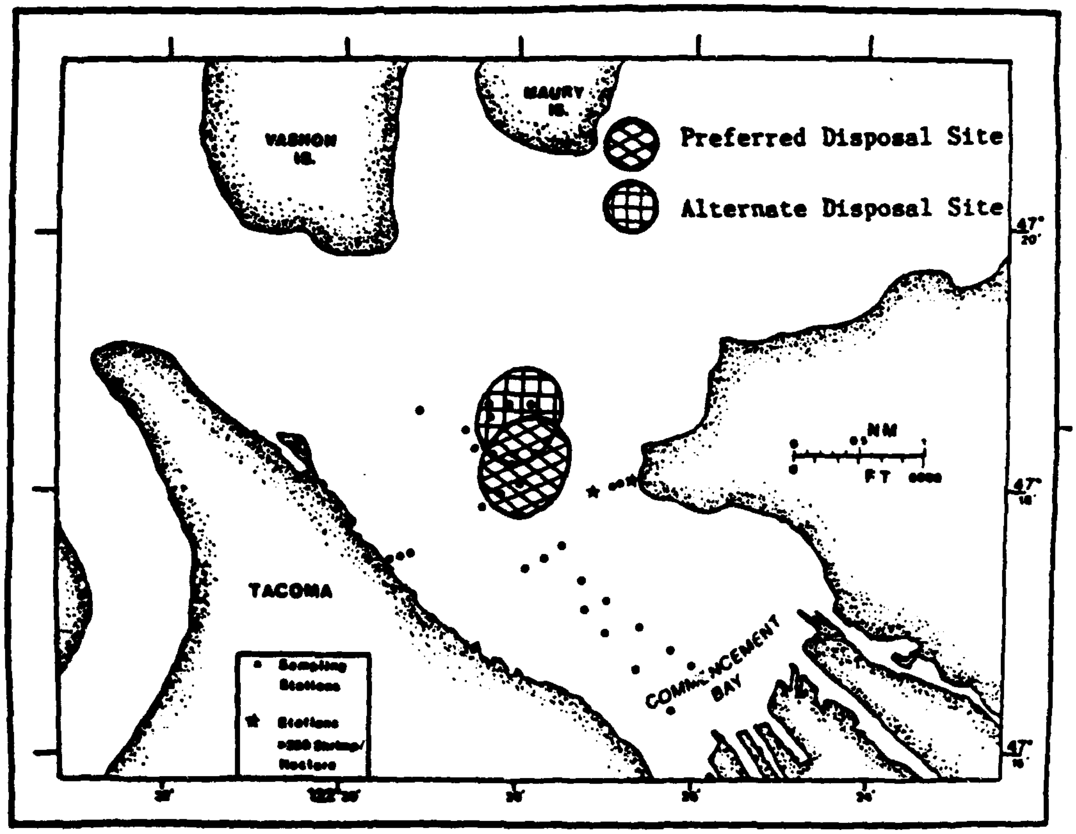


Figure II.10-40 **Commencement Bay combined shrimp distribution. Dots denote stations with shrimp populations below 250 per hectare and stars denote shrimp populations greater than 250 per hectare. (Source: adapted from Dinnel et al., 1986a-h)**

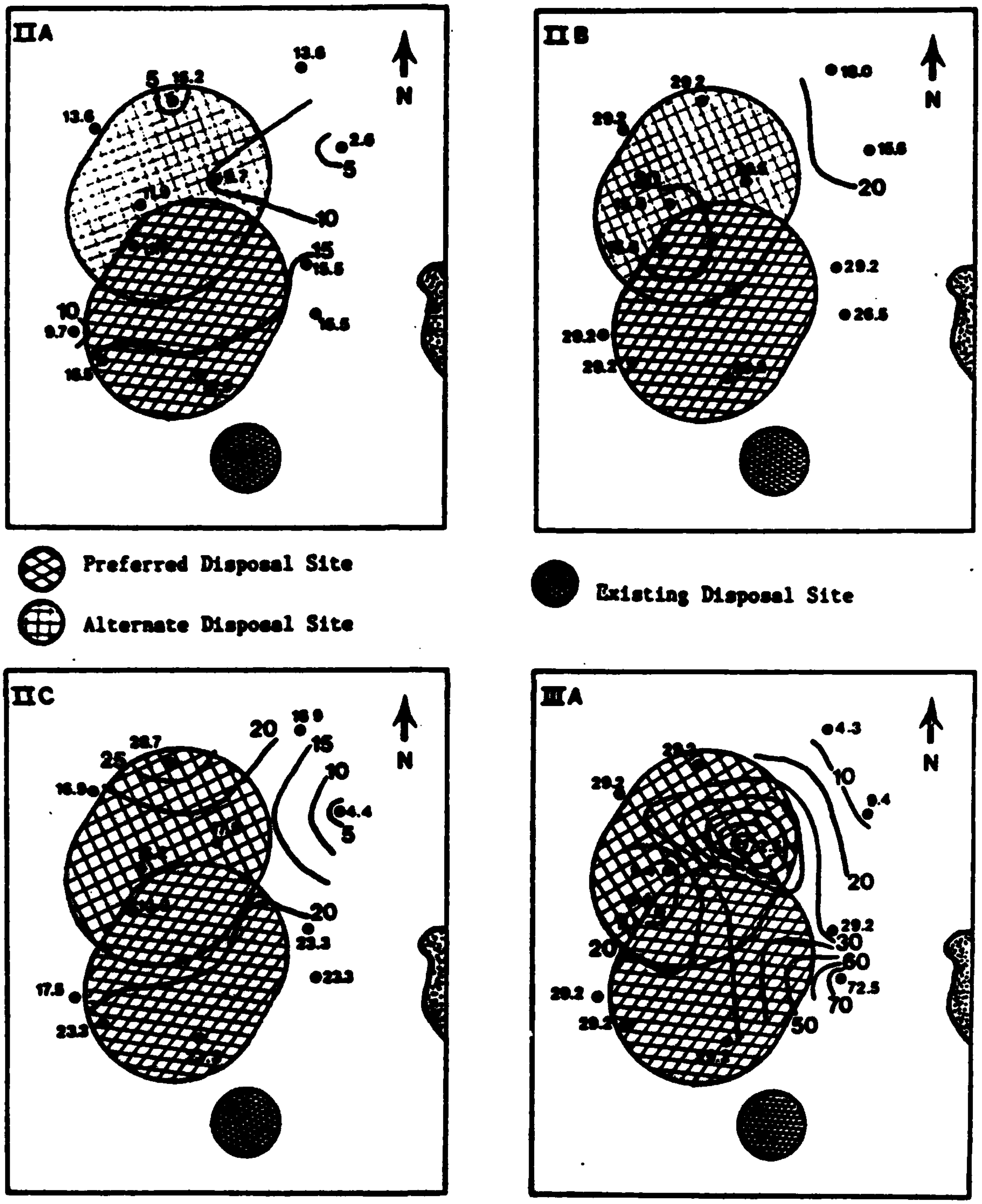


Figure II.10-41 Preferred and alternative disposal sites in Commencement Bay on benthic biomass potentially available to four grou[illegible] of fish (biomass in grams per square mete[illegible] (Source: adapted from Clarke, 1986)

REFERENCES

Adamec, Jr., S.A., B.H. Johnson, and M.J. Trawle. 1986. Dredged Material Disposal Study U.S. Navy Homeport. Draft Report HL-86-xx. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MI. 26 pp.

Armstrong, D.A. 1983. Cyclic Crab Abundances and Relationship to Environmental Causes. In: From Year to Year: Interannual Variability of the Environment and Fisheries of the Gulf of Alaska and the Bering Sea. W.W. Wooster (ed.). Washington Sea Grant Publ. WSG-WO-83-3. pp. 102-110.

Armstrong, D.A., and D.R. Gunderson. 1985. The Role of Estuaries in Dungeness Crab Early Life History: A Case Study in Grays Harbor, Washington. In: Proceedings of the Symposium on Dungeness Crab Biology and Management. University of Alaska, Alaska Sea Grant Rpt. No. 85-3. pp. 145-170.

Armstrong, D., J. Armstrong, and P. Dinnel. 1986. Diver Observations of Female Dungeness Crab Density at Ship Harbor and Adjacent Areas. Progress Report Series by Aquatic Research Consultant Services (ARCS) to Washington Dept. Fisheries.

Barnes, C.A. and C.C. Ebbesmeyer. 1978. Some Aspects of Puget Sound's Circulation and Water Properties. In: Estuarine Transport Processes (B. Kjerfve, ed.), University of South Carolina Press, Columbia, South Carolina. pp. 209-228.

Becker, D.S. 1984. Resource Partitioning by Small-Mouthed Pleuronectids in Puget Sound, Washington. Ph.D. Dissertation, Univ. Washington, Seattle, Washington. 139 pp.

Bendiner, W.P. 1975. Dispersion of Effluent from the West Point Outfall. Interim Report to Municipality of Metropolitan Seattle. University of Washington. Applied Physics Laboratory, 15 January 1975. 24 pp.

Bingham, C.R. 1978. Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington; Appendix G: Benthic Community Structural Changes Resulting From Dredged Material Disposal, Elliott Bay Disposal Site. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, Tech. Rep. D-77-24.

Bokuniewicz, H.J, J.A. Gebert, R.B. Gordon, J.L. Higgins, P. Kaminsky, C.C. Pilbeam, M.W. Reed and C. Tuttle. 1978. Field Study of the Mechanics of the Placement of Dredged Material at Open-Water Disposal Sites. Final Report. Tech. Rept. D-78-7. Vol. II: Appendices J-O. U.S. Army Corps of Engineers Waterways Experiment Station, Environmental Effects Lab., Vicksburg, Mississippi.

Borgeson, D.P. 1963. A Rapid Method for Foot Habit Studies. Trans. Amer. Fish. Soc. 92(4):434-435.

Bowers, G.W., and M.K. Goldenblatt. 1978. Calibration of a Predictive Model for Instantaneously Discharged Dredged Material. EPA-600/3-78-089, US Environmental Protection Agency, Corvallis, Oregon.

Brandsma, M.G., and D.J. Divoky. 1976. Development of Models for Prediction of Short-Term Fate of Dredged Material Discharged in the Estuarine Environment. Contract Report D-76-5, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Butler, H.L. 1980. Evolution of a Numerical Model for Simulating Long-Period Wave Behavior in Ocean-Estuarine Systems. In: Estuarine and Wetland Processes, P. Hamilton and K. Macdonald (eds.). Plenum Press, New York.

Cahill, R.W. Letter from R.W. Cahill, Washington Department of Fisheries to F. Urabeck, Seattle COE dated 22 January, 1986. 2 pages.

Carr, W.E.S. and C.A. Adams. 1973. Food Habits of Juvenile Marine Fishes Occupying Seagrass Beds in the Estuarine Zone Near Crystal River, Florida. Trans. Amer. Fish. Soc. 102:511-540.

Chan, Sin-Lam, M.H. Schiewe, K.L. Grams, A.J. Friedman, R.G. Bogar, U. Varanasi, W.L. Reichert, P.D. Plesha, S.J. Demuth, and D.W. Brown. 1986. East, West, and Duwamish Waterways Navigation Improvement Project: Physical/Chemical/Biological Analyses of Sediments Proposed for Dredging. NOAA, National Marine Fisheries Service report.

Clarke, D.G. 1986. Benthic Resources Assessment Technique Evaluation of Disposal Sites in Puget Sound and Adjacent Waters. Working Draft. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. September, 1986.

Coastal Zone Atlas. Washington State Department of Ecology. 1980. Coastal Zone Atlas of Washington, Vols. 1-12.

Code of Federal Regulations. 1984. Guidelines for Specification of Disposal Sites for Dredged or Fill Material.

Cooper Consultants, Inc. 1986. Checking Studies on Zones of Siting Feasibility for Dredged Material Disposal in Puget Sound. (Constract # xxxx). Environmental Protection Agency Region 10, Seattle, Washington.

Corps Sediment Records. NPDEN-GS-L, 78-5-4; and NPDEN-GS-L, 74S-59Q.

Cox, J.M., C.C. Ebbesmeyer, C.A. Coomes, J.M. Helseth, L.R. Hinchey, G.A. Cannon, and C.A. Barnes. May 1984. Synthesis of Current Measurements in Puget Sound, Washington Volume 1: Index to Current Measurements Made in Puget Sound from 1908-1980, with Daily and Record Averages for Selected Measurements. NOAA Technical Memorandum NOS OMS-3, Rockville, Maryland.

Crecelius, E.A., R.G. Reily, N.S. Bloom, and B.L. Thomas. 1985. History of Contamination of Sediments in Commencement Bay, Tacoma, Washington. NOAA Technical Memorandum NOS OMA 14.

Dahlstrom, W.A., and P.W. Wild. 1983. A History of Dungeness Crab Fisheries in California. Calif. Fish Game Bull., 172. pp. 7-24.

Dexter R.N., D.E. Anderson, and E.A. Quinlan. 1984. Long-term Impacts Induced by Disposal of Contaminated River Sediments in Elliott Bay, Seattle, Washington. Technical Report D-84-4. Prepared by URS Company for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Dinnel, P.A., D.A. Armstrong, and C. Dungan. 1985a. Initiation of a Dungeness Crab, Cancer magister, Habitat Study in North Puget Sound. In: Proceedings of the Symposium on Dungeness Crab Biology and Management. University of Alaska, Alaska Sea Grant Rpt. No. 85-3. pp. 327-337.

Dinnel, P.A., D.A. Armstrong, and R.O. McMillan. 1985b. Survey of Dungeness Crab, Cancer magister, in Oak Harbor, Washington. Final Rpt. to the Seattle District, U.S. Army Corps of Engineers by School of Fisheries, Univ. Washington, Seattle, Washington. 23 pp.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986a. U.S. Navy Homeport Disposal Site Investigations: Winter Cruise Report. Progress Report to the U.S. Navy by School of Fisheries, Univ. Wash., Seattle, Washington. 36 pp.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986b. U.S. Navy Homeport Disposal Site Investigations: Spring Cruise Report. Progess Report to the U.S. Navy by School of Fisheries, Univ. Wash., Seattle, Washington. 36 pp.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986c. U.S. Navy Homeport Disposal Site Investigations: Summer Cruise Report. Progress Report to the U.S. Navy by School of Fisheries, Univ. Wash., Seattle, Washington.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986d. U.S. Navy Homeport Disposal Site Investigations: Autumn Cruise Report. Progress Report to the U.S. Navy by School of Fisheries, Univ. Wash., Seattle, Washington.

Dinnel, P.A., D.A. Armstrong, R.S. Miller, and R.F. Donnelly. 1986e. Puget Sound Dredge Disposal Analysis (PSDDA) Disposal Site Investigations: Trawling Studies, Winter Cruise Report. Progress Report to the U.S. Navy by School of Fisheries, Univ. Wash., Seattle, Washington.

Dinnel, P.A., D.A. Armstrong, B. Miller, and R.F. Donnelly. 1986f. Puget Sound Dredge Disposal Analysis (PSDDA) Disposal Site Investigations: Trawling Studies, Summer Cruise Report. School of Fisheries and Fisheries Research Institute, University of Wash., Seattle, Washington.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986g. Puget Sound Dredge Disposal Analysis (PSDDA) Disposal Site Investigations: Trawling Studies, Fall Cruise Report. School of Fisheries and Fisheries Research Institute. University of Wash., Seattle, Washington.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986h. Puget Sound Dredge Disposal Analysis (PSDDA) Disposal Site Investigations: Phase 1 Trawl Studies Parts 1 and 2. Fisheries Research Institute, School of Fisheries, University of Wash., Seattle, Washington.

Dinnel, P.A., D.A. Armstrong, B.S. Miller, and R.F. Donnelly. 1986i. Puget Sound Dredge Disposal Analysis (PSDDA) Disposal Site Investigations: Phase I Trawl Studies in Saratoga Passage, Port Gardner, Elliott Bay and Commencement Bay, Washingon. Final Report. Fisheries Research Institute, School of Fisheries, University of Wash., Seattle, Washington.

Donnelly, R., B. Miller, R. Lauth, and J. Shriner. 1984. Fish Ecology. Vol. VI, Section 7. In: Renton Sewage Treatment Plant Project: Seahurst Baseline Study (Q.J. Stober and K.K. Chew, Eds.). Final Rpt. by Univ. Washington Fish. Res. Institute to METRO, FRI-UW-8413. 276 pp.

Ebbesmeyer, C.C., C.A. Coomes, J.M. Cox, J.M. Helseth, L.R. Hinchey, G.A. Cannon, and C.A. Barnes. 1984. Synthesis of Current Measurements in Puget Sound, Washington - Volume 3: Circulation in Puget Sound: An Interpretation Based on Historical Records of Currents. NOAA Technical Memorandum NOS OMS 5.

Ebbesmeyer, C.C., C.A. Coomes, J.M. Cox, E.T. Baker, C.S. Smyth, and C.A. Barnes. 1986. Dynamics of Commencement Bay and Approaches. NOAA Technical Memorandum NOS OMA 24. 79 pp.

English, T. 1976. Ecological Baseline and Monitoring Study for Port Gardner and Adjacent Waters: A Summary Report for the Years 1972 through 1976. Wash. Department Ecology Rpt. No. DOE 76-20.

English, T. Unpublished Data. Department of Oceanography, University of Washington.

Environmental Protection Agency/Army Corps of Engineers. 1984. General Approach to Designation Studies for Ocean Dredged Material Disposal Sites.

Envirosphere. 1986. Puget Sound Dredged Material Inventory System.

Evaluation Procedures Technical Appendix.

Ervine, G. Personal Communication. 29 July 1986.

Evans-Hamilton, Inc. 1985. Bibliography and Maps Pertinent to the Selection of Open Water Disposal Sites in the Greater Puget Sound Region. Draft, Volume I submitted to the Seattle District Corps of Engineers.

Evergreen Pacific. 1979. Scuba Divers Guide, Washington Waters. Straub Printing and Publishing, Seattle, Washington. 16 pp.

Gabriel, W.L. 1981. Feeding Selectivity of the Dover Sole, Microstomus pacificus, off Oregon. Fishery Bulletin 79:749-763.

Garber, C.S. 1984. Underwater Video Survey Analysis of Fourmile Rock Dredge Spoils Disposal. Unpublished ONR Report.

Gunderson, D.R., D.A. Armstrong, and C. Rogers. 1985. Sampling Design and Methodology for Juvenile Dungeness Crab Surveys. In: Proceedings of the Symposium on Dungeness Crab Biology and Management. University of Alaska, Alaska Sea Grant Rpt. No. 85-3. pp. 135-144.

Harman, R. 1985. Subtidal Communities In Central Puget Sound. Unpublished data sheets, diagrams and maps summarizing results of benthic samples taken throughout Puget Sound over the past 17 years. Shoreline Community College, Seattle, Washington.

Harman and Serwold. Unpublished.

Hileman, J., and M. Matta. 1983. Commencement Bay Deep Water Sediment Investigation: Tacoma, Washington, September 15-17, 1982. Environmental Protection Agency Region 10, Seattle, Washington.

Hinchey, L.R., C.C. Ebbesmeyer, J.M. Helseth, and J.M. Cox. 1980. Dynamics of Elliott Bay and Approaches, Washington. Prepared for URS Corporation, Seattle, WA.

Johnson, B.H. Personal Communication.

Johnson, B.H. In preparation. User's Guide for Dredged Material Disposal Models for Computing the Short-Term Physical Fate at Open Water Sites. Technical Report D-78-47, U.S. Army Engineer Waterways Experiment Station. Vicksburg, Mississippi.

Johnson, B.H., and B.W. Holliday. 1978. Evaluation and Calibration of the Tetra Tech Dredged Material Dispsoal Models Based on Field Data. TR-D-78-47, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Koh, R.C.Y., and Y.C. Chang. 1973. Mathematical Model for Barged Ocean Disposal of Waste. Environmental Protection Technology Series EPA 660/2-73-029. US Environmental Protection Agency, Washington, D.C.

Lavelle, J.W., G.J. Massoth, and E.A. Crecelius. 1986. Accumulation Rates of Recent Sediments in Puget Sound, Washington. Mar. Geol., 72:59-70.

Lincoln. 1979. Instruction and Operation Manual for the Puget Sound Model. University of Washington, Seattle, Washington. Reference M79-11.

Lunz, J.D. 1986. Application of the Benthic Resources Assessment Technique (BRAT) to the Foul Area Disposal Site. U.S.A. Engineer Waterways Experiment Station. Prepared for U.S.A. Engineer Division, New England.

Lunz, J.D., and D.R. Kendall. 1982. Benthic Resources Analysis Technique, a Method for Quantifying the Effects of Benthic Community Changes on Fish Resources. Conference Proceedings on Marine Pollution. Oceans, 1982, NOAA, Office of Marine Pollution Assessment, Rockville, Maryland. pp. 1021-1027.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, H.O. Hodgins, and S. L. Chan. 1982. Chemical Contaminates and Abnormalities in Fish and Invertebrates From Puget Sound. NOAA Tech. Memo. OMPA-19. 168 pp.

Mayer, D.L. 1973. The Ecology and Thermal Sensitivity of the Dungeness Crab, Cancer magister, and Related Species of its Benthic Community on Similk Bay. Ph.D. Dissertation, College of Fisheries, University of Washington, Seattle, Washington.

Mearns, A.J., and M.J. Allen. 1978. Use of Small Otter Trawls in Coastal Biological Surveys. Contribution No. 66, South. Calif. Coast. Water Res. Project. EPA-600/3-78-083.

Miller, B., and S. Borton. 1980. Geographical Distribution of Puget Sound Fishes: Maps and Data Source Sheets. Vols. 1-3. Washington Sea Grant Publ., U.W. Fish. Res. Institute, Seattle, Washington. 681 pp.

Moherek, A.J. 1978. Flume Experiments on Sand, Silt, and Clay Mixtures from the Offshore Dredged Material Disposal Site, Galveston, Texas. TR-D-78-34. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Management Plan Technical Appendix.

Northern Technical Services (NORTEC). Data on file for measurements near Elliott Bay. 14715 NE 95th Street, P.O. Box 3099, Redmond, Washington 98052.

Northern Technical Services (NORTEC). 1986. U.S. Navy Deep-Delta Confined Aquatic Disposal Site Current Monitoring Study (Draft Report). Prepared for Howard Needles, Tamman, and Bergendoff.

Rattray, M., Jr. and J.H. Lincoln. 1955. Operating Characteristics of an Oceanographic Model of Puget Sound. Trans. of Amer. Geophys. Union, 36:251-261.

Revised Code of Washington.

Roberts, R.W. 1979. Subtidal Grain-Size Maps of Puget Sound. Dept. of Oceanography, University of Washington.

Schell, W.R., E.E. Collias, A. Nevissi, and C.C. Ebbesmeyer. 1976. Trace Contaminants from Duwamish River Dredge Spoils Deposited off Fourmile Rock in Elliott Bay. College of Fisheries and Department of Oceanography, University of Washington. For METRO, Seattle, Washington.

Schmalz, R.A., Jr. 1983. The Development of a Numerical Solution to the Transport Equation Report 1 Methodology. Miscellaneous Paper CERC-83-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Schmalz, R.A., Jr. 1986. A Numerical Investigation of Astronomic Tide in Puget Sound. TR-CERC-85-XX. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Sheng, Y.P. 1983. Mathematical Modelling of Three-Dimensional Coastal Currents and Sediment Dispersion: Model Development and Application. CERC Technical Report CERC-83-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Sheridan, P.F. 1979. Trophic Resource Utilization by Three Species of Sciaenid fishes in a Northwest Florida Estuary. Northeast Gulf Sci. 3:1-5.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry: The Principle and Practice of Statistics in Biological Research. W. H. Freeman and Company, San Francisco.

Southard, J.B., R.A. Young, C.D. Hollister. 1971. Experimental Erosion of Calcareous Ooze. Jour. Geophys. Res., 76(24):5903-5909.

Standard Methods for the Examination of Water and Wastewater. 1985. 16th Edition. pp. 97-98, 418-419, 525-532.

Sternberg, R.W. 1972. Predicting Initial Motion and Bedload Transport of Sediment Particles in Shallow Marine Environment, Chapter 3. In: Shelf Sediment Transport, edited by Swift, Duane, and Pilkey. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pennsylvania.

Sternberg, R.W. and E.E. Collias. 1973. Deposition of Dredge Spoils in Dana Passage, Washington. University of Washington Department of Oceanography Final Report.

Stober, Q.J., and K.K. Chew. 1984. Renton Sewage Treatment Plant Project: Duwamish Head. Fisheries Research Institute, FRI-UW-8417. University of Washington, Seattle, Washington.

Striplin, P.L., M.E. Day, and J.Q. Word. 1985. Benthic Communities and Sediment Stability in the Region of the Proposed Duwamish Head Outfall, Seattle, Washington. Report to URS Engineers.

Striplin, P.L., P. Sparks-McConkey, and M.E. Day. 1987. Puget Sound Sediment Deposition Analysis, Final Report. For the Army Corps of Engineers, Seattle, Washington. 77pp.

Sundborg, A. 1967. Some Aspects of Fluvial Sediments and Fluvial Morphology, I. General Views and Graphic Methods. Geografiska Annaler, 49, Series A, 2-4.

Sweeny, R.A. 1978. Aquatic Disposal Field Investigation Ashtabula River Disposal Site, Ohio. Technical Report D-77-42 to US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Tatem, H.E. 1984. Long-Term Impact of Dredged Material at Two Open-Water Sites: Lake Erie and Elliott Bay, Evaluative Summary. Technical Report D-84-5. Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

Tatem, H.E. and J. Johnson. 1978. Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington. Technical Report D-77-24. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Tetra Tech, Inc. 1985. Everett Harbor Action Plan: Initial Data Summaries and Problem Identification. Draft Report TC-3991-03. Environmental Protection Agency Region 10, Seattle, Washington.

Tetra Tech, Inc. 1985c. Commencement Bay Nearshore/tideflats Remedial Investigation. Vol. 1. Washington State Department of Ecology and U.S. Environmental Protection Agency.

Tetra Tech, Inc. 1986. Elliott Bay Toxics Action Plan: Initial Data Summaries and Problem Identification. Draft Report TC-3991-01. Environmental Protection Agency Region 10, Seattle, Washington.

Title 40 Protection of the Environment, Part 230, Section 404(b)(1) of the Clean Water Act.

Trawle, M.J., and B.H. Johnson. 1986. Puget Sound Generic Dredged Material Disposal Alternatives. Miscellaneous Paper HL-86-5. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

U.S. Army Corps of Engineers. 1985. DAMOS, Disposal Area Monitoring System, Overview of the Program, U.S. Army Corps of Engineers, Waltham, Massachusetts.

Washington Administration Code. 1983. Open Water Disposal Sites. WAC 332-30-166. Volume 7.

Washington Marine Atlas

Washington State Dept. of Fisheries. 1986. Technical Report Number 79, as amended. Salmon, Groundfish, and Shellfish Resources in Puget Sound.

Weitkamp, D.E. and T.H. Schadt. 1981. Commencement Bay Studies Technical Studies: Volume III, Fish and Wetlands. Report to the U.S. Army Corps of Engineers, Seattle District. Appendices, 75 pp.

Weitkamp, D.E., D. McEntee, and R. Whitman. 1986. Dungeness Crab Survey of Everett Harbor and Vicinity, 1984-1985. Department of the Navy by Parametrix, Inc., Bellevue, Washington.

Wild, P.W., P.M.W. Law, and D.R. McLain. 1983. Variations in Ocean Climate and the Dungeness Crab Fishery in California. Calif. Fish Game Bull., 172. pp. 175-188.

Wild, P.W., and R.N. Tasto (Eds.). 1983. Life History, Environment, and Mariculture Studies of the Dungeness Crab, Cancer magister, with Emphasis on the Central California Fishery Resource. Calif. Fish Game Bull. 172. 352 pp.

Word, J.Q., P.L. Striplin, K. Keeley, J. Ward, P. Sparks-McConkey, L. Bentler, S. Hulsman, K. Li, J. Schroeder, and K. Chew. 1984a. Subtidal Benthic Ecology. Final Report. Vol. V, Section 6, in Q.J. Stober and K.K. Chew. Principal Investigators. Renton Sewage Treatment Plant Project: Seahurst Baseline Study. Fisheries Research Institute, University of Washington, FRI-UW-8413.

Word, J.Q., P.L. Striplin, J. Ward, and P.J. Sparks. 1984b. Subtidal Benthic Ecology. Final Report Chapter 6. In J. Stober and K.K. Chew. Principal Investigators. Renton Sewage Treatment Plant Project: Duwamish Baseline Study. Fisheries Research Institute, University of Washington, FRI-UW-8417. pp. 134-189.

PART IV

GLOSSARY OF TERMS AND ABBREVIATIONS

PUGET SOUND DREDGED DISPOSAL ANALYSIS (PSDDA)
GLOSSARY OF TERMS

Amphipods. Small shrimp-like crustaceans (for example, sand fleas). Many live on the bottom, feed on algae and detritus, and serve as food for many marine species. Amphipods are used in laboratory bioassays to test the toxicity of sediments.

Apparent Effects Threshold. The sediment concentration of a contaminant above which statistically significant biological effects would always be expected.

Area Ranking. The designation of a dredging area relative to its potential for having sediment chemicals of concern. Rankings range from "low" potential to "high" potential, and are used to determine the intensity of dredged material evaluation and testing that might be required.

Baseline Study. A study designed to document existing environmental conditions at a given site. The results of a baseline study may be used to document temporal changes at a site or document background conditions for comparison with another site.

Bathymetry. Shape of the bottom of Puget Sound expressed as the spatial pattern of water depths. Bathymetric maps are essentially topographic maps of the bottom of Puget Sound.

Benthic Organisms. Organisms that live in or on the bottom of a body of water.

Bioaccumulation. The accumulation of contaminants in the tissues of an organism. For example, certain chemicals in food eaten by a fish tend to accumulate in its liver and other tissues.

Bioassay. A laboratory test used to evaluate the toxicity of a material (commonly sediments or wastewater) by measuring behavioral, physiological, or lethal responses of organisms.

Biota. The animals and plants that live in a particular area or habitat.

Bottom-Dump Barge. A barge that disposes of dredged material by opening along a center seam.

Bottomfish. Fish that live on or near the bottom of a body of water, for example, English sole.

Bulk Chemical Analyses. Chemical analyses performed on an entire sediment sample, without separating water from the solid material in a sample.

Capping. See confined aquatic disposal.

Carcinogenic. Capable of causing cancer.

Clamshell Dredging. Scooping of the bottom sediments using a mechanical clamshell bucket of varying size. Commonly used in fine grain sediments and calm water, the sediment is dumped onto a separate barge and towed to a disposal site when disposing in open water.

Code of Federal Regulations. The compilation of Federal regulations adopted by Federal agencies through a rule-making process.

Compositing. Mixing sediments from different samples to produce a composite sample for chemical and/or biological testing.

Confined Disposal. A disposal method that isolates the dredged material from the environment. Confined disposal may be in aquatic, nearshore, or upland environments.

Confined Aquatic Disposal (CAD). Confined disposal in a water environment. Usually accomplished by placing a layer of sediment over material that has been placed on the bottom of a water body (i.e., capping).

Contaminant. A chemical or biological substance in a form or in a quantity that can harm aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.

Contaminated Sediment.

Technical Definition: A sediment that contains measurable levels of contaminants.

Management or Common Definition: A sediment that contains sufficient quantities of contaminants to result in adverse environmental effects and thus require restriction(s) for dredging and/or disposal of dredged material (e.g., is unacceptable for unconfined, open water disposal or conventional land/shore disposal, requiring confinement).

Conventional Nearshore Disposal. Disposal at a site where dredged material is placed behind a dike in water along the shoreline, with the final elevation of the fill being above water. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Conventional Pollutants. Sediment parameters and characteristics that have been routinely measured in assessing sediment quality. These include sulfides, organic carbon, etc.

Conventional Upland Disposal. Disposal at a site created on land (away from tidal waters) in which the dredged material eventually dries. Upland sites are usually diked to confine solids and to allow surface water from the disposal operation to be released. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Depositional Analysis. A scientific inspection of the bottom sediments that identifies where natural sediments tend to accumulate.

Depositional Area. An underwater region of Puget Sound where material sediments tend to accumulate.

Disposal. See confined disposal, conventional nearshore disposal, conventional upland disposal, and unconfined, open-water disposal.

Disposal Site. The bottom area that receives discharged dredged material; encompassing, and larger than, the target area and the disposal zone.

Disposal Site Work Group. The PSDDA work group that is designating locations for open-water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible.

Disposal Zone. The area that is within the disposal site that designates where surface release of dredged material will occur. It encompasses the smaller target area. (See also "target area" and "disposal site".)

Dredged Material. Sediments excavated from the bottom of a waterway or water body.

Dredged Material Management Unit. The maximum volume of dredged material for which a decision on suitability for unconfined open-water disposal can be made. Management units are typically represented by a single set of chemical and biological test information obtained from a composite sample. Management units are smaller in areas of higher chemical contamination concern (see "area ranking").

Dredger. A private or public agency conducting dredging (ports, Corps of Engineers, etc.). (Compare to "local sponsor".)

Dredging. Any physical digging into the bottom of a water body. Dredging can be done with mechanical or hydraulic machines and is performed in many parts of Puget Sound for the maintenance of navigation channels that would otherwise fill with sediment and block ship passage.

Disposal Site Work Group. The PSDDA work group that is designating locations for open-water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible.

Ecosystem. A group of completely interrelated living organisms that interact with one another and with their physical environment. Examples of ecosystems are a rain forest, pond, and estuary. An ecosystem, such as Puget Sound, can be thought of as a single complex system. Damage to any part may affect the whole. A system such as Puget Sound can also be thought of as the sum of many interconnected ecosystems such as the rivers, wetlands, and bays. Ecosystem is thus a concept applied to various scales of living communities and signifying the interrelationships that must be considered.

Effluent. Effluent is the water flowing out of a contained disposal facility. To distinguish from "runoff" (see below) due to rainfall, effluent usually refers to water discharged during the disposal operation.

Elutriate. The extract resulting from mixing water and dredged material in a laboratory test. The resulting elutriate can be used for chemical and biological testing to assess potential water column effects of dredged material disposal.

Entrainment. The addition of water to dredged material during disposal, as it descends through the water column.

Environmental Impact Statement. A document that discusses the likely significant environmental impacts of a proposed project, ways to lessen the impacts, and alternatives to the proposed project. EIS's are required by the National and State Environmental Policy Acts.

Erosion. Wearing away of rock or soil via gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical and chemical forces.

Estuary. A confined coastal water body where ocean water is diluted by inflowing fresh water, and tidal mixing occurs.

Evaluation Procedures Work Group. The PSDDA work group that is developing chemical and biological testing and test evaluation procedures for dredged material assessment.

Gravid. Having eggs, such as female crabs carrying eggs.

Ground Water. Underground water body, also called an aquifer. Aquifers are created by rain which soaks into the ground and flows down until it collects at a point where the ground is not permeable.

Habitat. The specific area or environment in which a particular type of plant or animal lives. An organism's habitat provides all of the basic requirements for life. Typical Puget Sound habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself.

Hazardous Waste. Any solid, liquid, or gaseous substance which, because of its source or measurable characteristics, is classified under state or Federal law as hazardous, and is subject to special handling, shipping, storage, and disposal requirements. Washington State law identifies two categories of hazardous waste: dangerous and extremely hazardous. The latter category is more hazardous and requires greater precautions.

Hopper Dredge. A hydraulic suction dredge that is used to pick up coarser grain sediments (such as sand), particularly in less protected areas with sea swell. Dredged materials are deposited in a large holding tank or "hopper" on the same vessel, and then transported to a disposal site. The hopper dredge is rarely used in Puget Sound.

Hydraulic Dredging. Dredging accomplished by the erosive force of a water suction and slurry process, requiring a pump to move the water-suspended sediments. Pipeline and hopper dredges are hydraulic dredges.

Hydraulics Project Approval. RCW 75.20.100 Approval from the Washington Department of Fisheries and Washington Department of Game for the use, diversion, obstruction or change in the natural flow or bed of any river or stream, or that will use any salt or fresh waters of the state.

Hydraulically Dredged Material. Material, usually sand or coarser grain, that is brought up by a pipeline or hopper dredge. This material usually includes slurry water.

Hydrocarbon. An organic compound composed of carbon and hydrogen. Petroleum and its derived compounds are hydrocarbons.

Infauna. Animals living in the sediment.

Intertidal Area. The area between high and low tide levels. The alternate wetting and drying of this area makes it a transition between land and water organisms and creates special environmental conditions.

Leachate. Water or other liquid that may have dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. Rainwater that percolates through a sanitary landfill and picks up contaminants is called the leachate from the landfill.

Local Sponsor. A public entity (e.g., port district) that sponsors Federal navigation projects. The sponsor seeks to acquire or hold permits and approvals for disposal of dredged material at a disposal site.

Loran C. An electronic system to facilitate navigation positioning and course plotting/tracking.

Management Plan Work Group. The PSDDA work group is developing a management plan for each of the open-water dredged material disposal sites. The plan will define the roles of local, State, and Federal agencies. Issues being addressed include: permit reviews, monitoring of permit compliance, treatment of permit violations, monitoring of environmental impacts, responding to unforeseen effects of disposal, plan updating, and data management.

Material Release Screen. A laboratory test proposed by PSDDA to assess the potential for loss of fine-grained particles carrying chemicals of concern from the disposal site during disposal operations.

Mechanical Dredging. Dredging by digging or scraping to collect dredged materials. A clamshell dredge is a mechanical dredge. (See "hydraulic dredging.")

Metals. Metals are naturally occurring elements. Certain metals, such as mercury, lead, nickel, zinc, and cadmium, can be of environmental concern when they are released to the evironment in unnatural amounts by man's activities.

__Microlayer, Sea Surface Microlayer__. The extremely thin top layer of water that can contain high concentrations of natural and other organic substances. Contaminants such as oil and grease, many lipophylic (fat or oil associated) toxicants, and pathogens may be present at much higher concentrations in the microlayer than they are in the water column. Also the microlayer is biologically important as a rearing area for marine organisms.

__Microtox__. A laboratory test using luminescent bacteria and measuring light production, used to assess toxicity of sediment extracts.

__Molt__. A complex series of events that results in the periodic shedding of the skeleton, or carapace by crustaceans (all arthropods for that matter). Molting is the only time that many crustaceans can grow and mate (particularly crabs).

__Monitor__. To systematically and repeatedly measure something in order to detect changes or trends.

__Nutrients__. Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to accelerated growth of algae and subsequent degradation of water quality due to oxygen depletion. Some nutrients can be toxic at high concentrations.

__Overdepth Material__. Dredged material removed from below the dredging depth needed for safe navigation. Through overdepth is incidentally removed due to dredging equipment precision, its excavation is usually planned as part of the dredging project to ensure proper final water depths. Common overdepth is 2 feet below the needed dredging line.

__Oxygen Demanding Materials__. Materials such as food waste and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes. Chemical and biological oxygen demand (COD and BOD, respectively) are different measures of how much oxygen demand a substance has.

__Parameter__. A quantifiable or measurable characteristic of something. For example, height, weight, sex, and hair color are all parameters that can be determined for humans. Water quality parameters include temperature, pH, salinity, dissolved oxygen concentration, and many others.

__Pathogen__. A disease-causing agent, especially a virus, bacteria, or fungi. Pathogens can be present in municipal, industrial, and nonpoint source discharges to the Sound.

__Permit__. A written warrant or license, granted by an authority, allowing a particular activity to take place. Permits required for dredging and disposal of dredged material include the U.S. Army Corps of Engineers Section 404 permit, the Washington State Department of Fisheries Hydraulics Permit, the city or county Shoreline Development Permit, and the Washington Department of Natural Resources Site Use Disposal Permit.

Persistent. Compounds that are not readily degraded by natural physical, chemical, or biological processes.

Pesticide. A general term used to describe any substance, usually chemical, used to destroy or control organisms (pests). Pesticides include herbicides, insecticides, algicides, and fungicides. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.

pH. The degree of alkalinity or acidity of a solution. Water has a pH of 7.0. A pH of less than 7.0 indicates an acidic solution, and a pH greater than 7.0 indicates a basic solution. The pH of water influences many of the types of chemical reactions that occur in it. Puget Sound waters, like most marine waters, are typically pH neutral.

Phase I. The PSDDA study is divided into two, 2-year long, overlapping phases. Phase I covers the central area of Puget Sound including Seattle, Everett, and Tacoma. Phase I began in April 1985.

Phase II. The PSDDA study is divided into two, 2-year long, overlapping phases. Phase II covers the North and South Sound (including, Olympia, Bellingham, and Port Angeles)—the areas not covered by Phase I. Hood Canal is not being considered for location of a disposal site. Phase II began in April 1986.

Pipeline Dredge. A hydraulic dredge that transports slurried dredged material by pumping it via a pipe. (See "hydraulic dredge".)

Point Source. Locations where pollution comes out of a pipe into Puget Sound.

Polychaete. A marine worm.

Polychlorinated Biphenyls. A group of manmade organic chemicals, including about 70 different but closely related compounds made up of carbon, hydrogen, and chlorine. If released to the environment, they persist for long periods of time and can concentrate in food chains. PCB's are not water soluble and are suspected to cause cancer in humans. PCB's are an example of an organic toxicant.

Polycyclic (Polynuclear) Aromatic Hydrocarbon. A class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAH's are commonly formed by forest fires and by the combustion of fossil fuels. PAH's often reach the environment through atmospheric fall-out, highway runoff, and oil discharge.

Priority Pollutants. Substances listed by EPA under the Clean Water Act as toxic and having priority for regulatory controls. The list includes toxic metals, inorganic contaminants such as cyanide and arsenic, and a broad range of both natural and artificial organic compounds. The list of priority pollutants includes substances that are not of concern in Puget Sound, and also does not include all known harmful compounds.

Puget Sound Water Quality Authority. An agency created by the Washington State legislature in 1985 and tasked with developing a comprehensive plan to protect and enhance the water quality of Puget Sound. The Authority adopted its first plan in January 1987.

Range Markers. Pairs of markers which, when aligned, provide a known bearing to a boat operator. Two pairs of range markers can be used to fix position at a point.

Regional Administrative Decisions. A term used in PSDDA to describe decisions that are a mixture of scientific knowledge and administrative judgment. These region-wide policies are collectively made by all regulatory agencies with authority over dredged material disposal to obtain Sound-wide consistency.

Regulatory Agencies. Federal and State agencies that regulate dredging and dredged material disposal in Puget Sound, along with pertinent laws/permits, include:

U.S. Army Corps of Engineers

- River and Harbor Act of 1899 (Section 10 permits)
- Clean Water Act (Section 404 permits)

U.S. Environmental Protection Agency

- Clean Water Act (Section 404 permits)

Washington Department of Natural Resources

- Shoreline Management Act (site use permits)

Washington Department of Ecology

- Clean Water Act (Section 401 certifications)
- Shoreline Management Act (CZMA consistency determinations)

Washington Department of Fisheries

- Hydraulics Project Approval

Washington Department of Game

- Hydraulics Project Approval

Local shoreline jurisdiction e.g., City of Seattle, City of Everett, Pierce County

- Shoreline permit to non-Federal dredger/DNR

U.S. Fish and Wildlife Service (Key reviewing agency)

National Marine Fisheries Service (Key reviewing agency)

The Resource Conservation and Recovery Act. The Federal law that regulates solid and hazardous waste.

Respiration. The metabolic processes by which an organism takes in and uses oxygen and releases carbon dioxide and other waste products.

Revised Code of Washington. The compilation of the laws of the State of Washington published by the Statute Law Committee.

Runoff. Runoff is the liquid fraction of dredged materials or the flow/seepage caused by precipitation landing on and filtering through upland or nearshore dredged material disposal sites.

Salmonid. A fish of the family Salmonidae. Fish in this family include salmon and trout. Many Puget Sound salmonids are anadromous, spending part of their life cycles in fresh water and part in marine waters.

Sediment. Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound. Sediment input to Puget Sound comes from natural sources, such as erosion of soils and weathering of rock, or anthropogenic sources, such as forest or agricultural practices or construction activities. Certain contaminants tend to collect on and adhere to sediment particles. The sediments of some areas around Puget Sound contain elevated levels of contaminants.

Spot Checking. Inspections on a random basis to verify compliance with permit requirements.

State Environmental Policy Act. A State law intended to minimize environmental damage. SEPA requires that State agencies and local governments consider environmental factors when making decisions on activities, such as development proposals over a certain size. As part of this process, environmental documents such as EIS's are prepared and opportunities for public comment are provided.

Statistically Significant. A quantitative determination of the statistical degree to which two measurements of the same parameter can be shown to be different, given the variability of the measurements.

Subtidal. Refers to the marine environment below low tide.

Suspended Solids. Organic or inorganic particles that are suspended in water. The term includes sand, mud, and clay particles as well as other solids suspended in the water column.

Target Area. The specified area on the surface of Puget Sound for the disposal of dredged material. The target area is within the disposal zone and within the disposal site.

Toxic. Poisonous, carcinogenic, or otherwise directly harmful to life.

Toxic Substances and Toxicants. Chemical substances, such as pesticides, plastics, detergents, chlorine, and industrial wastes that are poisonous, carcinogenic, or otherwise harmful to life if found in sufficient concentrations.

Treatment. Chemical, biological, or mechanical procedures applied to an industrial or municipal discharge or to other sources of contamination to remove, reduce, or neutralize contaminants.

Turbidity. A measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. Very high levels of turbidity can be harmful to aquatic life.

Unconfined, Open-Water Disposal. Discharge of dredged material into an aquatic environment, usually by discharge at the surface, without restrictions or confinement of the material once it is released.

Variable Range Radar. Radar equipped with markers which allow measurement of bearings and distances to known targets.

Vessel Traffic Service (VTS). A network of radar coverage for ports of Puget Sound operated by the Coast Guard to control ship traffic. Most commercial vessels are required to check in, comply with VTS rules, and report any change in movement.

Volatile Solids. The material in a sediment sample that evaporates at a given high temperature.

Washington Administrative Code. Contains all State regulations adopted by State agencies through a rule-making process. For example, Chapter 173-201 WAC contains water quality standards.

Water Quality Certification. Approval given by Washington State Department of Ecology which acknowledges the compliance of a discharge with Section 401 of the Clean Water Act.

Waterways Experiment Station (WES). Corps of Engineers (Corps) research facility located in Vicksburg, Mississippi, that performs research and support projects for the various Corps districts.

Wetlands. Habitats where the influence of surface or ground water has resulted in development of plant or animal communities adapted to such aquatic or intermittently wet conditions. Wetlands include tidal flats, shallow subtidal areas, swamps, marshes, wet meadows, bogs, and similar areas.

Zoning. To designate, by ordinances, areas of land reserved and regulated for specific land uses.

ABBREVIATIONS

BATTELLE	Battelle Marine Research Laboratory
BOD	Biochemical Oxygen Demand
BRAT	Benthic Resources Assessment Technique
CFR	Code of Federal Regulations
CI	Confidence Interval
cm	centimeters
cm/s	Centimeters per second
COE	U.S. Army Corps of Engineers
COOPER	Cooper Consultants Inc.
DIFID	Disposal From an Instantaneous
DMRP	Dredged Material Research Program
DOTS	Dredging Operations Technical Support Program
DSWG	Disposal Site Work Group
EHI	Evans-Hamilton, Inc.
EIS	Environmental Impact Statement
ENVIROSPHERE	Envirosphere, a division of Ebasco, Inc.
EPA	U.S. Environmental Protection Agency, Region 10
EPWG	Evaluation Procedures Work Group
METRO	Municipality of Metropolitan Seattle
mg/l	milligram/liter
MPWG	Management Plan Work Group
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration
NOAA-IMS	NOAA-PMEL-Institute for Marine Studies
NOAA-OAD	NOAA
NOAA-PMEL	NOAA - Pacific Marine Environmental Laboratory
NOS	National Ocean Survey
PCB	Polychlorinated Biphenyls
PHI	Grain size classification
PIERCE CO.	Pierce County
PMFC	Pacific Marine Fisheries Commission
POS	Port of Seattle
PSA	Puget Sound Alliance
PSDDA	Puget Sound Dredge Disposal Analysis
PSWQA	Puget Sound Water Quality Authority
REMOTS	Remote Environmental Monitoring of the Sea Floor
RPA	Resource Planning Associates
SEPA	Washington State Environmental Policy Act
SND	Standard Normal Deviates
SUQUAMISH	Suquamish Indian Tribe
t-CB	Total PCB
TPM	Total Particulate Matter
TVS	Total Volatile Solids
USFWS	U.S. Fish and Wildlife Service
UWFISH	University of Washington School of Fisheries
WAC	Washington Administrative Code
WDF	Washington State Department of Fisheries
WDNR	Washington State Department of Natural Resources
WDOE	Washington State Department of Ecology
WPPA	Washington Public Ports Association
ZSF or ZSFs	Zone(s) of Siting Feasibility
Pb	Lead 210 isomer

3-CB Trichlorobiphenyls
36-263 Private Citizen, Voting District

CONVERSION FACTORS FOR UNITS OF MEASUREMENT

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic feet per second	0.02831685	cubic meters per second
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
feet per second (fps)	0.5921	knots
fathoms	6.00	feet
square meters	0.0001	hectare
hectare	2.47	acres

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Curtis Ebbesmeyer
Susan Ebbesmeyer
Doug Evans
Kamuron Gural
Robert Hamilton
Keith Kurrus
Douglas Navetski
Toni Proctor
Gary Rosenthal
Cindy Sanford
Jim Sanford
Pamela Sparks-McConkey
Peter Striplin
Clay Wilson

EXHIBIT A

BIOLOGICAL CHARACTERISTICS AT EXISTING DISPOSAL SITES

A variety of biological studies have been conducted at or near the existing DNR designated disposal sites in central Puget Sound. Several studies were accomplished at the outer Commencement Bay site prior to the Superfund studies in the nearshore area. The inner Commencement Bay site was closed in late 1973 after receiving an estimated maximum of 38,000 cubic yards during that year. Biological data at the existing sites within the three areas comes largely from several general studies (Word et al., 1984; Tetra Tech, 1985, 1986; Battelle, 1986) and PSDDA field studies.

A. Port Gardner

Tetra Tech (1985) found that total abundance and taxa of the benthic infauna did not differ significantly from their reference site, but did find that amphipod abundance was increased. Dinnel (1986) found large numbers of female Dungeness crab on the site. Garber (1984) documented numerous fish and benthic invertebrates on and around the site using an underwater television system.

Several biological studies have been conducted on or near the existing site by PSDDA due to its location relative to the alternative PSDDA site. See Sections II.8 and II.9 for the results of those studies.

B. Fourmile Rock

Battelle (1986) examined the number of benthic infaunal species and number of individuals at the site and at a reference area (Dabob Bay) with comparable substrate and water depths. The site had a mean of 9 species and 18 individuals while Dabob Bay had 11 species and 18 individuals. Although the report implies that the site is low in terms of taxa and individuals, in fact the difference between the means for both sets of data fall well within the range of both data sets and hence are probably not statistically different. In fact the site is also probably no different than the shallow reference site, Samish Bay. The two stations 17 and 20 used throughout for comparison to the site chemistry have a mean of 8.5 species with a range well within the ranges of the other stations and Dabob Bay (Battelle, 1986).

PSDDA conducted seasonal trawls to document epibenthic invertebrates and bottomfishes at the alternative site, which covered the Fourmile Rock site. Benthic resource values were also investigated at the PSDDA sites with some of the stations

being located within the existing site. See Sections II.8 and II.9 for the results.

C. Commencement Bay

PSDDA conducted seasonal trawls to document epibenthic invertebrates and bottomfishes at the PSDDA sites located near the existing disposal site. Benthic resource values were also investigated at the preferred and alternative PSDDA sites to assess bottomfish feeding habitat potential. See Sections II.8 and II.9 of the document for the results of those studies.

EXHIBIT B

MAPPING AND OVERLAY PROCESS: SITE SELECTION FACTORS

1. PRELIMINARY MAPS

Zones of Siting Feasibility were selected through a mapping approach which involved superimposing overlays to locate areas of few or no conflicts. The selected areas had minimal conflicts with the site selection factors. The DSWG examined a series of preliminary maps as an aid to decide which key factors should be shown on the final maps which were used for ZSF selections. The following factors were mapped:

a. Human Uses:	Maps Prepared:
1. Designated navigation lanes/channels/anchorage areas, approaches and high density vessel traffic areas.	Navigation lanes and areas of high density traffic
2. Recreational uses (fishing, sailing courses, diving sites, anchorage areas, artificial reefs, shoreline parks).	Underwater recreation areas/state parks/artificial reefs
3. Cultural/historical sites (wrecks and historical areas).	Shipwrecks
4. Aquaculture facilities and designated aquaculture areas.	DNR aquaculture sites
5. Utilities (pipelines and cables).	Utility corridors
6. Areas of special scientific importance (natural preserves, sanctuaries).	No map
7. Point pollution sources (outfalls and designated zones of initial dilution including municipal and industrial outfalls).	Major outfalls
8. Water supply (salt water intakes).	Major intakes
9. Compatibility of dredged disposal with local shoreline master programs, aesthetics, noise.	Shoreline designations

10. Political boundaries (counties, cities, Indian reservations, international border).	Political boundaries
11. Costs of transportation to disposal sites.	Dredge disposal transportation costs from Everett/Seattle/Tacoma
12. Beneficial effects of long-term disposal (beach replenishment, habitat creation, etc.).	No map

b. Biological Resources:

13. Food fish/shellfish harvest areas(commercial and recreational - using WDF and tribal description).	Shellfish harvesting areas, salmon fishing areas and non-salmonoid harvesting areas
14. Threatened and endangered species.	Bald eagle nest sites
15. Food fish and shellfish habitat (critical breeding, rearing, nursery and migration).	Shellfish critical habitats, non-groundfish critical habitats and groundfish critical habitats
16. Wetlands, mudflats, vegetated shallows.	Vegetated shallows and nearshore wetlands

c. Physical Parameters:

17. Bathymetry.	Bathymetry at one fathom contours
18. Substrata (physical, chemical and benthic sediment characteristics).	Long-term monitoring stations, sediment sampling stations, surface sediments, areas of elevated sediment chemistry
19. Current patterns and water circulation.	Current meter stations, maximum and net surface currents, maximum and net currents near bottom.

1.1 Final Maps

Of the above maps, sixteen which displayed key factors were selected and were subsequently used to identify the ZSFs. The key maps selected were:

(1) Political boundaries
(2) Shoreline designations under Shoreline Management Act
(3) Navigation lanes
(4) Areas of high density traffic
(5) Bathymetry
(6) Underwater/recreation areas
(7) Dredge sites/transportation costs
(8) Utilities
(9) Outfalls
(10) WDNR aquaculture sites
(11) Shellfish critical habitats
(12) Shellfish harvesting areas
(13) Non-Groundfish critical habitats
(14) Salmon (commercial and recreational fishing)
(15) Groundfish critical habitat
(16) Non-salmonoid harvesting areas

1.2 Additional Maps Used to Adjust ZSF Boundaries

The key maps were verified by the participating agencies. They were then overlayed and the ZSFs defined after applying the constraints noted in Section II.1.3. Further refinement of the ZSF boundaries was made by placing twelve additional overlay maps successively over the ZSF base map. No ZSF modifications were needed as a result of this process. These maps were:

(1) Shipwrecks
(2) Current meter stations
(3) Net surface currents
(4) Net near bottom currents
(5) Flood tide current patterns
(6) Ebb tide current patterns
(7) Long-term monitoring stations
(8) Sediment sampling stations
(9) Surface sediments
(10) Areas of elevated sediment chemistry
(11) Vegetated shallows and nearshore wetlands
(12) Bald eagle nest sites

The DSWG first defined the ZSFs by avoiding vulnerable resources and areas of human uses, and second by considering transportation haul costs. There was no weighting of the factors.

Using this procedure, no ZSF could be located within ten nautical miles of Everett due to the apparent presence of Dungeness Crab and non-salmonid harvesting areas (ground fish and fin fish). However, because data used to map crab and bottomfish resources had been quite limited (i.e., studies largely limited to shallower water depths), the DSWG believed there was a reasonable chance of locating an acceptable disposal site if field studies were made. Accordingly, a ZSF was defined near Everett, in Port Gardner, using the bathymetry map to outline the area lying between 120 and 600 feet, and a 2500 feet buffer from shore. Finally, the ZSFs that were identified were ranked either priority (1) or (2) as described in Part I, Section 2.8.

Further adjustment of the ZSFs was made by the DSWG as a result of input from: Federal; state and local agencies; Indian tribes; interest groups; scientists; and citizens. This input was received at DSWG meetings.

2. DESCRIPTION OF OVERLAY MAPS

At the 26 September 1985 workshop eighteen maps were distributed (nine covering the north section of the Phase I area, and nine covering the south section; maps 1-9 as described below). Map numbers 10 and 11 were not presented at the workshop because they could not be reduced in size and retain usable detail; therefore, they were made available at the COE Seattle Distict Office. A map showing the geographic features of Puget Sound is shown in Figure B-1.

The maps have been reproduced here as they were distributed at the workshop. Map No. 10, which was originally done at one fathom (6 foot) intervals, has been redrawn for clarity at 10 fathom intervals. Map No. 11 is also shown as adapted from Roberts (1979).

2.1 Map No. 1 (Fig. B-2)

Political Boundaries, Shoreline Master Plans, Shoreline Parks, Tribal Fisheries. Categories mapped are described below.

Boundaries for: (1) cities; (2) counties; (3) outer harbors; (4) Muckleshoot Indians; (5) Swinomish Indians; (6) Lummi Indians; (7) Yakima Indians; (8) Stillaguamish Indians; (9) Puyallup Indians; (10) Lower Elwha Indians.

Areas of shoreline master plans: (1) aquatic; (2) commercial; (3) conservancy; (4) conservancy management; (5) conservancy natural; (6) conservancy recreation; (7) diverse resource management area; (8) industrial; (9) natural; (10)

residential; (11) rural; (12) semi-rural; (13) shoreline residential; (14) suburban; (15) urban; (16) urban developed; (17) urban recreational; (18) urban residential; (19) urban stable; (20) urban undeveloped.

These areas were defined from master plans obtained from each city or county.

2.2 Map No. 2 (Fig. B-3)

Navigation Lanes, Areas of High Density Traffic, Utilities. Categories mapped include: (1) navigation lanes; (2) ferry routes; (3) tug routes; (4) pipe lines; (5) cables; (6) potential marinas; (7) ports.

These were compiled from NOAA nautical charts, the Washington Marine Atlas, and information from COE.

2.3 Map No. 3 (Fig. B-4)

Shipwrecks, Underwater Parks, Scuba Sites, Artificial Reefs. Categories mapped include: (1) shipwrecks; (2) underwater parks; (3) scuba sites; and (4) artificial reefs.

Shipwrecks, underwater parks, and scuba sites were identified from a diving guide (Evergreen Pacific, 1979), artificial reefs were located using data from DNR.

2.4 Map No. 4 (Fig. B-5)

Point Pollution Sources, Long-Term Monitoring Stations, Saltwater Intakes. Categories mapped include: (1) municipal sources; (2) industrial sources; (3) water sources; (4) sediment sources; (5) point pollution sources; (6) long-term monitoring stations; and (7) saltwater intakes.

Data were taken from NPDES permits and the Municipality of Metropolitan Seattle.

2.5 Map of Dredging Transportation Costs (Fig. B-6)

This map shows the estimated cost to transport a cubic yard of dredged material the following distances: 2, 4, and 6 nautical miles (one nautical mile equals 6076 feet). The distance, in cost, is shown as circular arcs from Everett, Duwamish River Mouth, and Commencement Bay.

The cost for dredging a cubic yard of material was estimated to be $1.80 from COE records. The cost for transporting a cubic yard over a distance of one nautical mile was determined to be $0.25; thus, the cost to haul a cubic yard a distance of 10 nautical miles equals $2.50, or approximately 139% of the dredging cost.

2.6 Map No. 5 (Fig. B-7)

Groundfish Critical Habitats, Non-Groundfish Critical Habitats, Bald Eagle Nest Sites. Subjects mapped include: (1) herring spawning areas; (2) herring holding areas; (3) smelt spawning beaches; (4) groundfish critical habitats; (5) non-groundfish critical habitats; and (6) bald eagle nest sites.

The first five items were from WDF Technical Report No. 79, and locations of bald eagle nests were obtained from the Washington Department of Game.

2.7 Map No. 6 (Fig. B-8)

Shellfish Habitats, Aquaculture Sites. Subjects mapped include: (1) geoducks; (2) other clams; (3) oysters; (4) mussels; (5) shrimp; (6) crab; (7) shellfish habitats; and (8) aquaculture sites.

Aquaculture sites were mapped from data supplied by DNR, and all other data were taken from Technical Report No. 79.

2.8 Map No. 7 (Fig. B-9)

Fin Fish Harvesting Areas. Subjects mapped include: (1) salmon commercial; (2) salmon recreational; and (3) non-salmonoid.

These maps were adapted from data contained in Technical Report No. 79.

2.9 Map No. 8 (Fig. B-10)

Vegetated Shallows/Wetlands. Subjects mapped include: (1) salt marshes; (2) sea grass; and (3) kelp.

These maps were adapted from the Coastal Zone Atlas (1979).

2.10 Map No. 9 (Fig. B-11)

Current Meter Stations, Net Surface Currents, Net Near-Bottom Currents. Subjects mapped include: (1) current meter stations; (2) net surface currents; and (3) net near-bottom currents.

2.11 Map No. 10 (Fig. B-12)

Bathymetry.

The original maps produced for PSDDA were done at a one fathom contour interval (one fathom equals six feet). The maps shown in Figure II.2-11 have been redrawn at a ten fathom interval for clarity. The DSWG in its selection of the ZSFs used the finely contoured charts (one fathom interval).

These bathymetry charts were compiled by the U.S. Navy during the 1940's using data collected prior to World War II.

2.12 Map No. 11 (Fig. B-13)

Surface Sediments.

These maps were reproduced from Roberts (1979). The data were collected from the Strait of Juan de Fuca and the Puget Sound region and depict the surface sediments in the Phase I area.

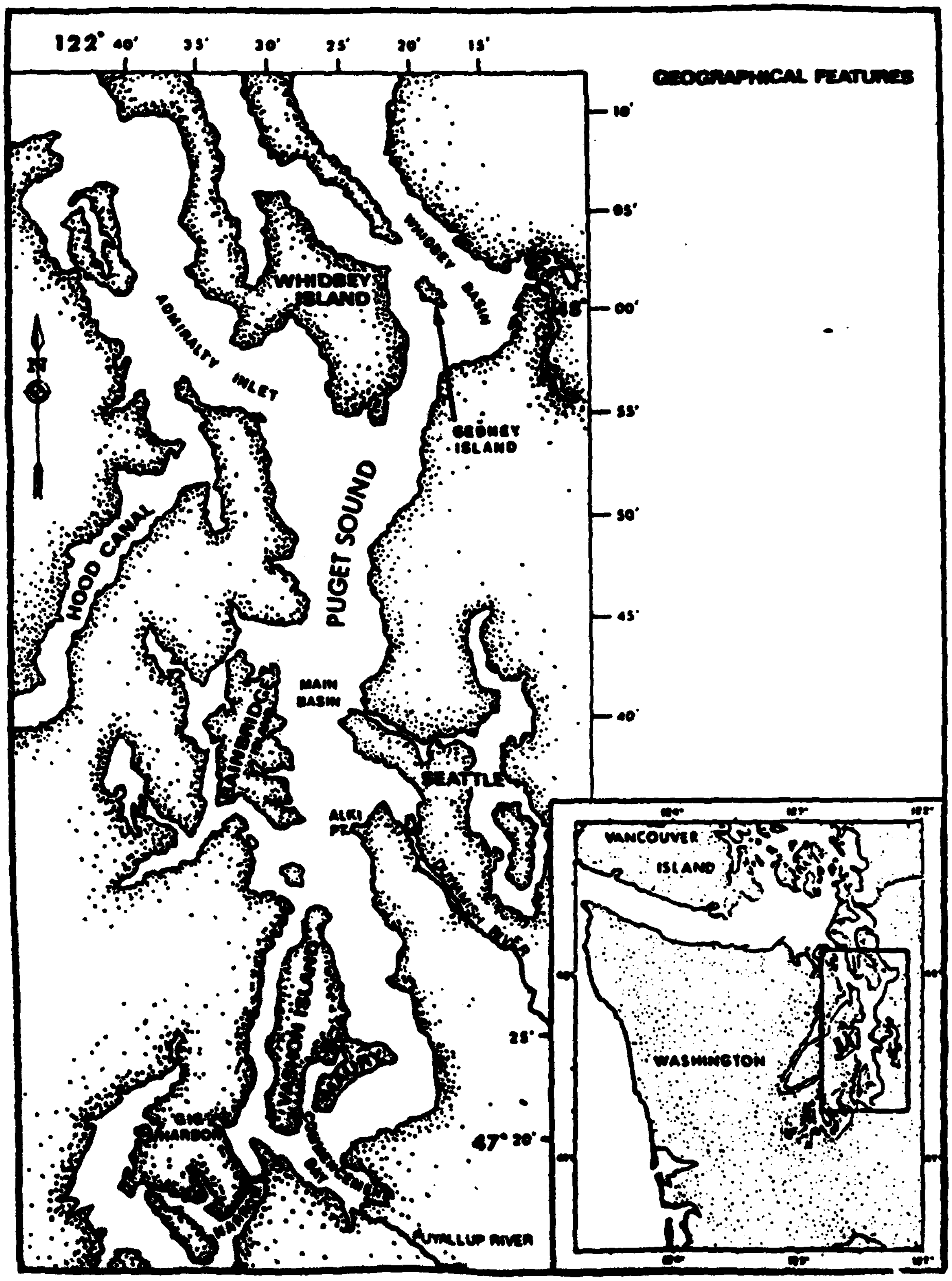
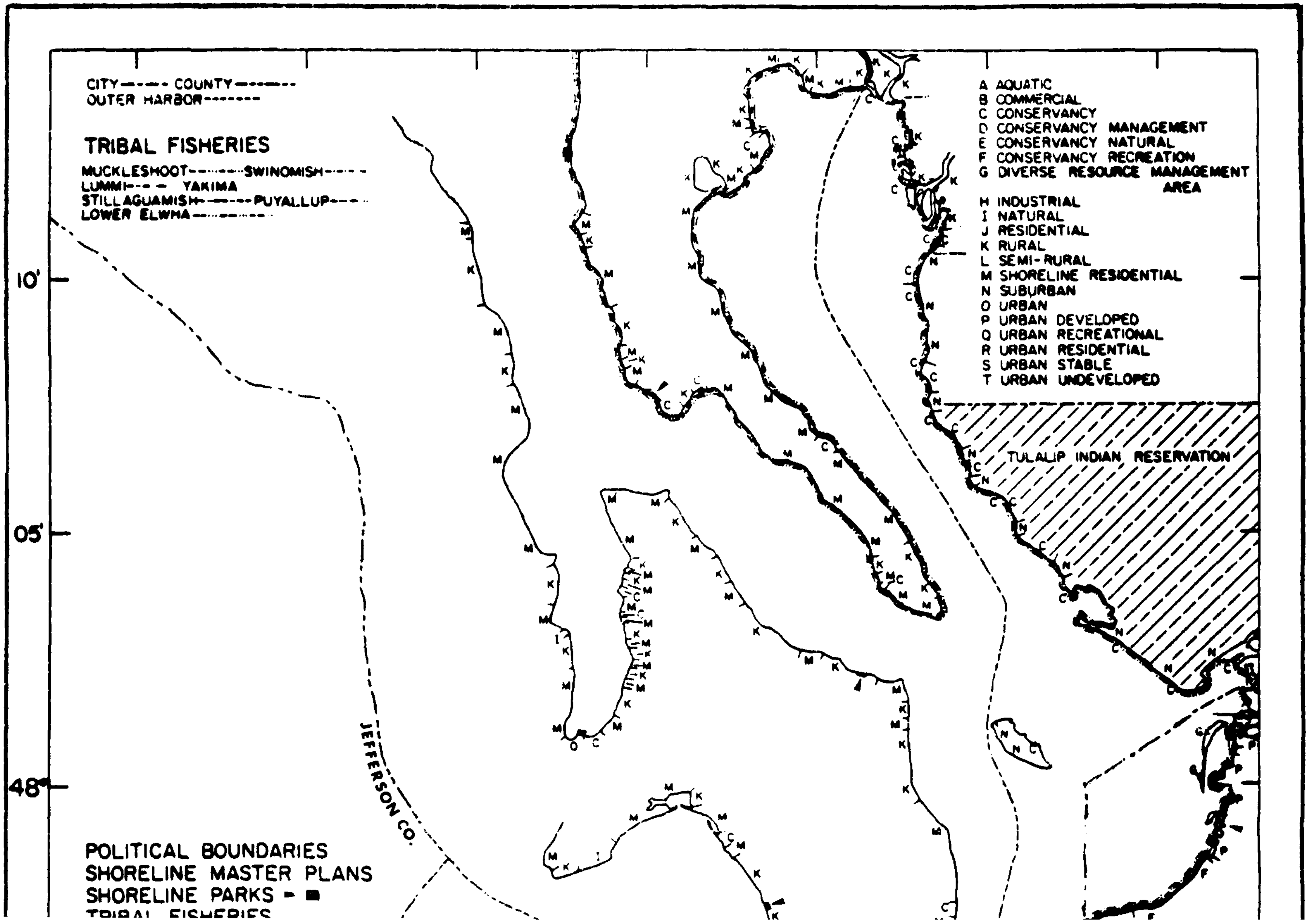


Figure B-1 Geographic features of Puget Sound.
(Source: EMI)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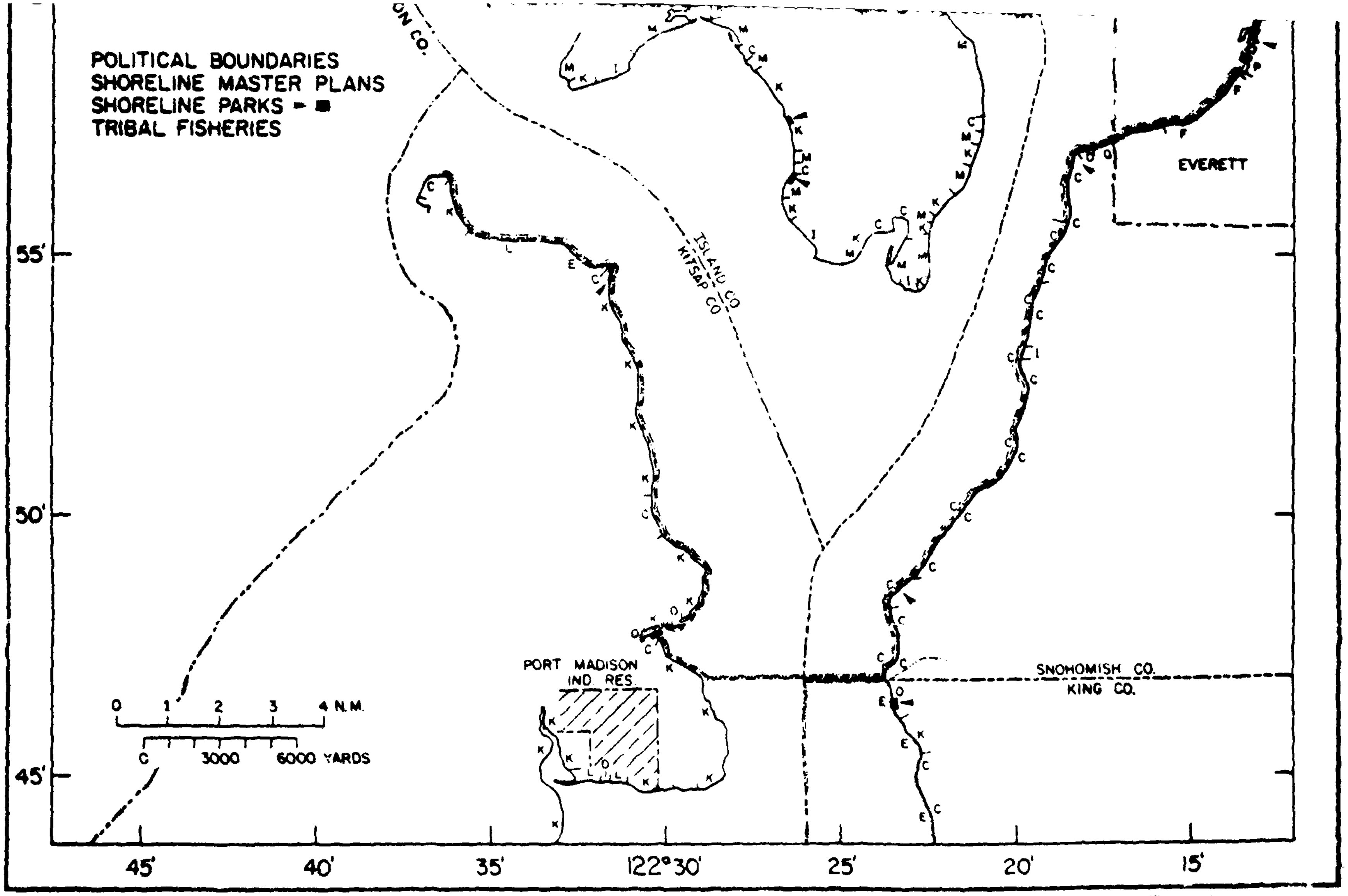
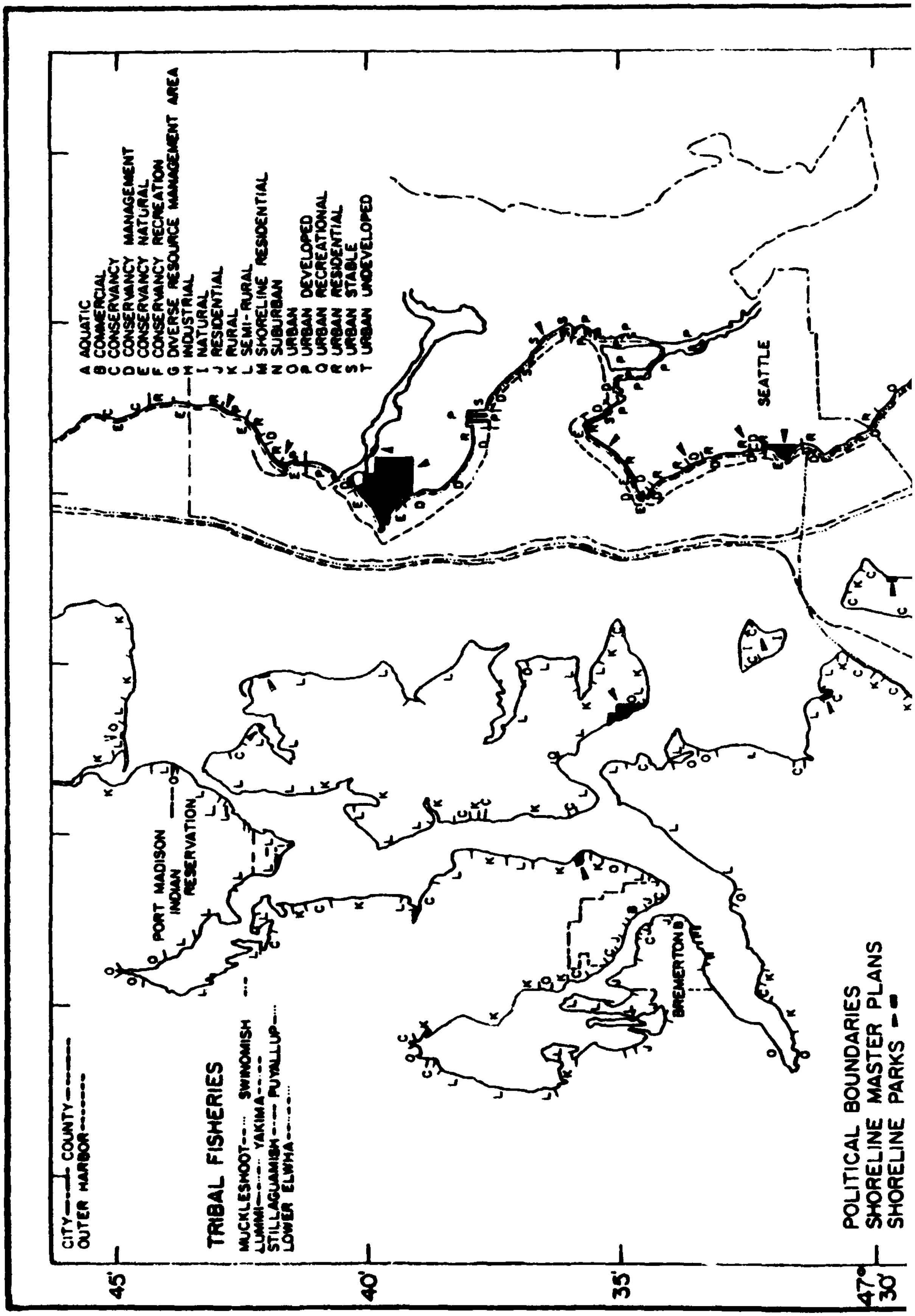
OUTER HARBOR -------
TRIBAL FISHERIES
MUCKLESHOOT -------- SWINOMISH -----
LUMMI ---- YAKIMA
STILLAGUAMISH ------ PUYALLUP ----
LOWER ELWHA --------
A AQUATIC
B COMMERCIAL
C CONSERVANCY
D CONSERVANCY MANAGEMENT
E CONSERVANCY NATURAL
F CONSERVANCY RECREATION
G DIVERSE RESOURCE MANAGEMENT AREA
H INDUSTRIAL
I NATURAL
J RESIDENTIAL
K RURAL
L SEMI-RURAL
M SHORELINE RESIDENTIAL
N SUBURBAN
O URBAN
P URBAN DEVELOPED
Q URBAN RECREATIONAL
R URBAN RESIDENTIAL
S URBAN STABLE
T URBAN UNDEVELOPED
TULALIP INDIAN RESERVATION
JEFFERSON CO.
10'
05'
48°
POLITICAL BOUNDARIES
SHORELINE MASTER PLANS
SHORELINE PARKS
TRIBAL FISHERIES


POLITICAL BOUNDARIES
SHORELINE MASTER PLANS
SHORELINE PARKS
TRIBAL FISHERIES
EVERETT
ISLAND CO
KITSAP CO
SNOHOMISH CO.
KING CO.
PORT MADISON
IND RES
0 1 2 3 4 N.M.
0 3000 6000 YARDS
55'
50'
45'
45'
40'
35'
122°30'
25'
20'
15'


A AQUATIC
B COMMERCIAL
C CONSERVANCY
D CONSERVANCY MANAGEMENT
E CONSERVANCY NATURAL
F CONSERVANCY RECREATION
G DIVERSE RESOURCE MANAGEMENT AREA
H INDUSTRIAL
I NATURAL
J RESIDENTIAL
K RURAL
L SEMI-RURAL
M SHORELINE RESIDENTIAL
N SUBURBAN
O URBAN
P URBAN DEVELOPED
Q URBAN RECREATIONAL
R URBAN RESIDENTIAL
S URBAN STABLE
T URBAN UNDEVELOPED
CITY COUNTY
OUTER HARBOR
TRIBAL FISHERIES
MUCKLESHOOT SWINOMISH
LUMMI YAKIMA
STILLAGUAMISH PUYALLUP
LOWER ELWHA
PORT MADISON INDIAN RESERVATION
SEATTLE
BREMERTON
POLITICAL BOUNDARIES
SHORELINE MASTER PLANS
SHORELINE PARKS
45'
40'
35'
47° 30'

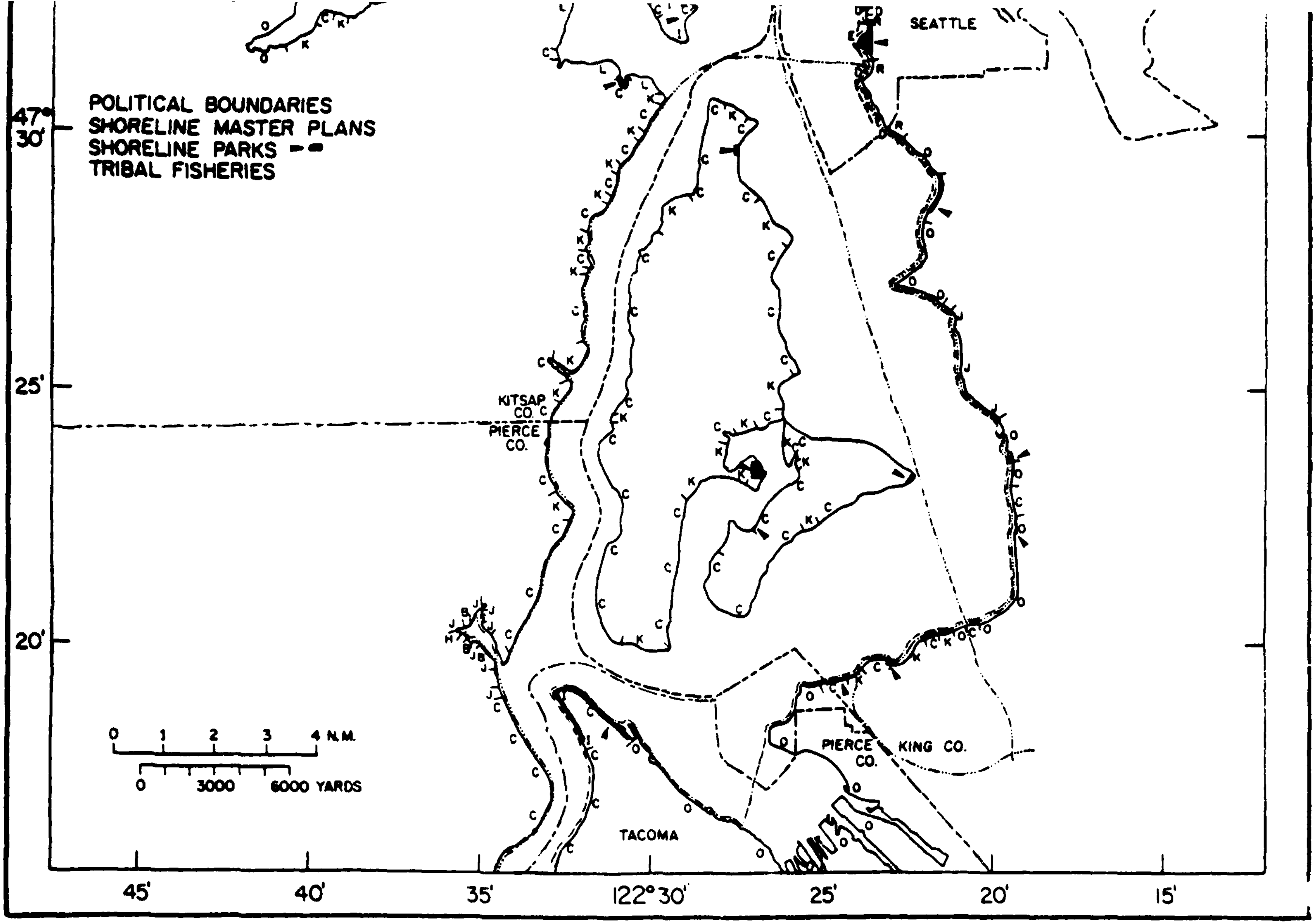
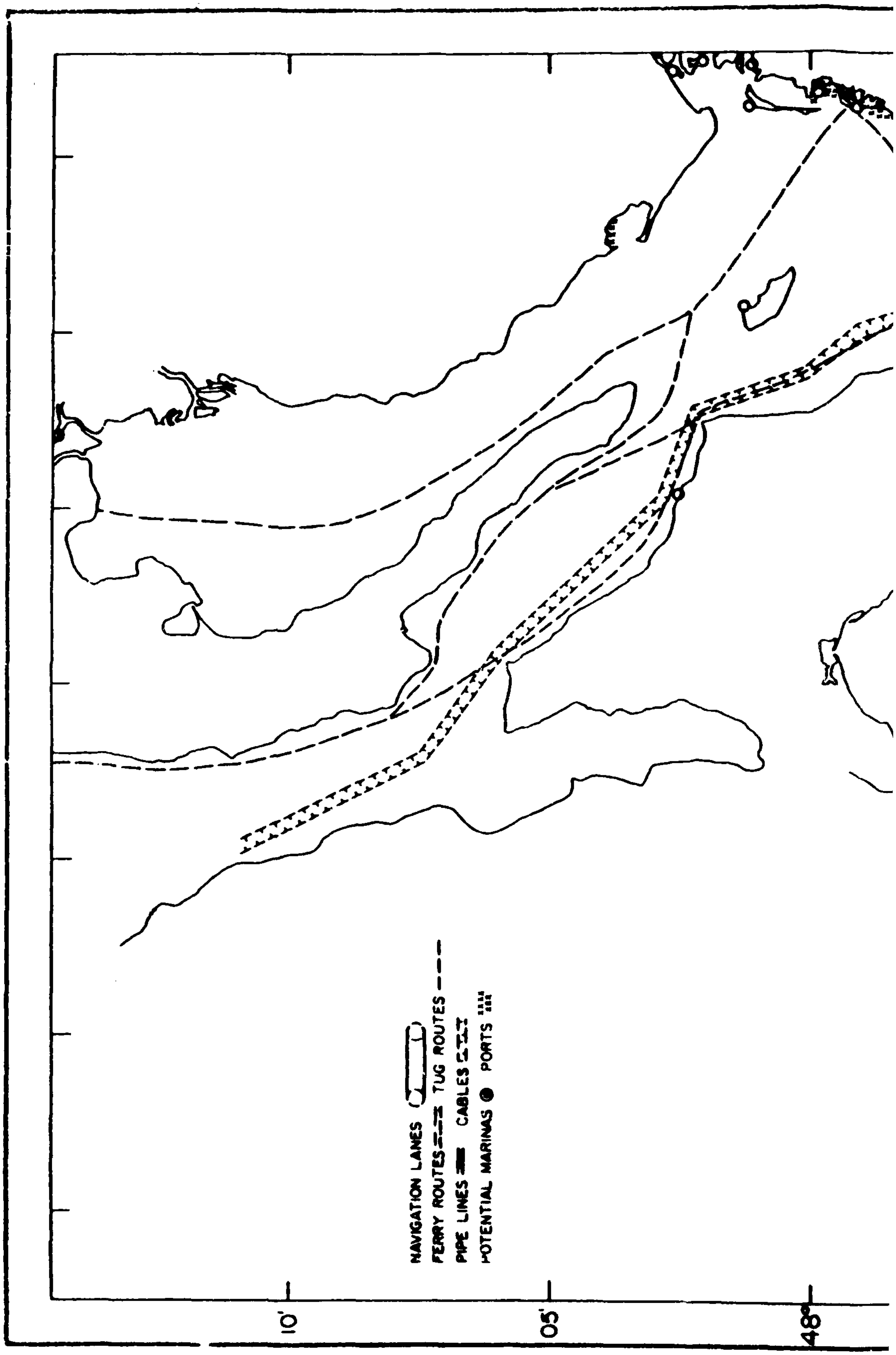
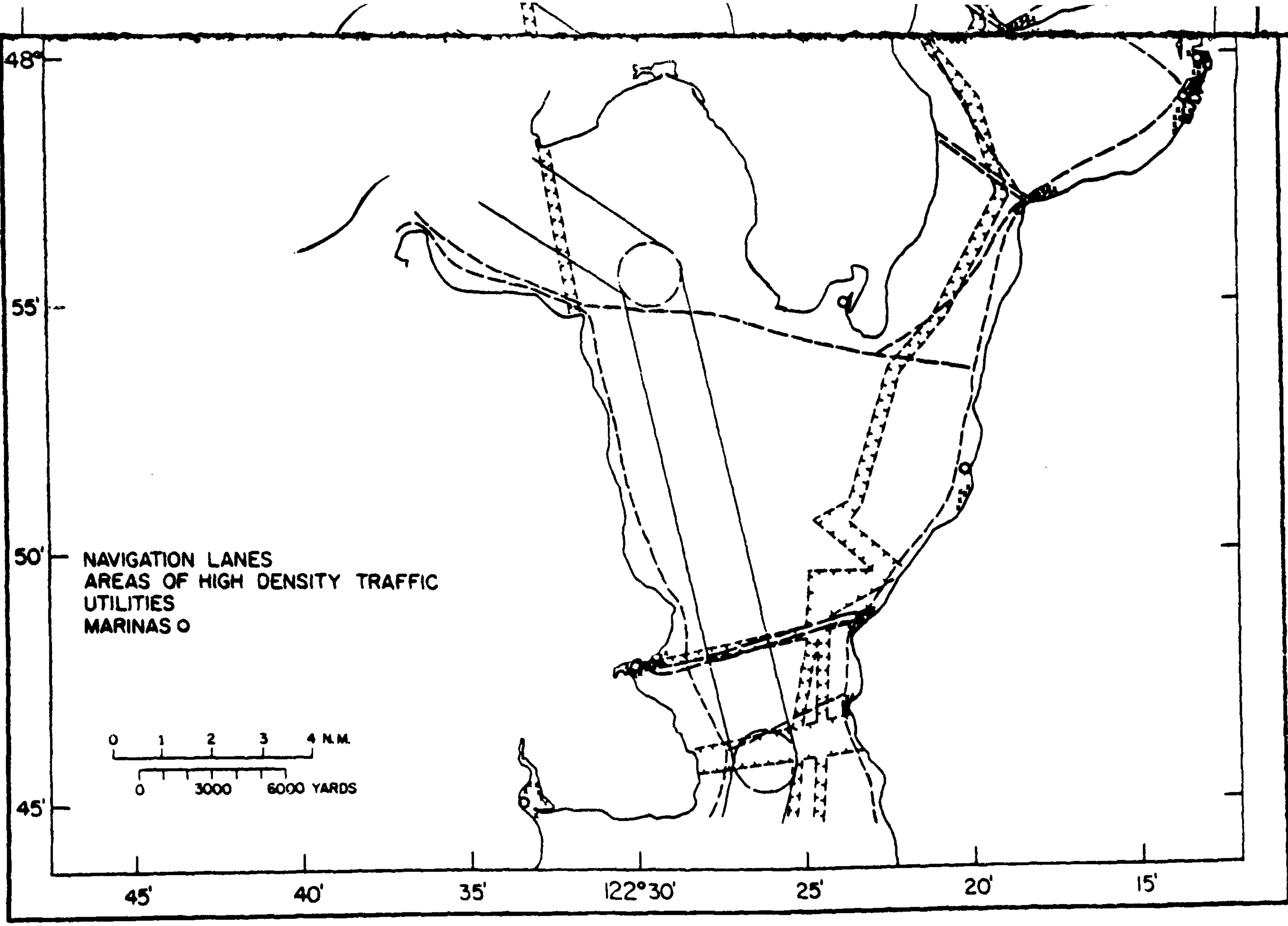
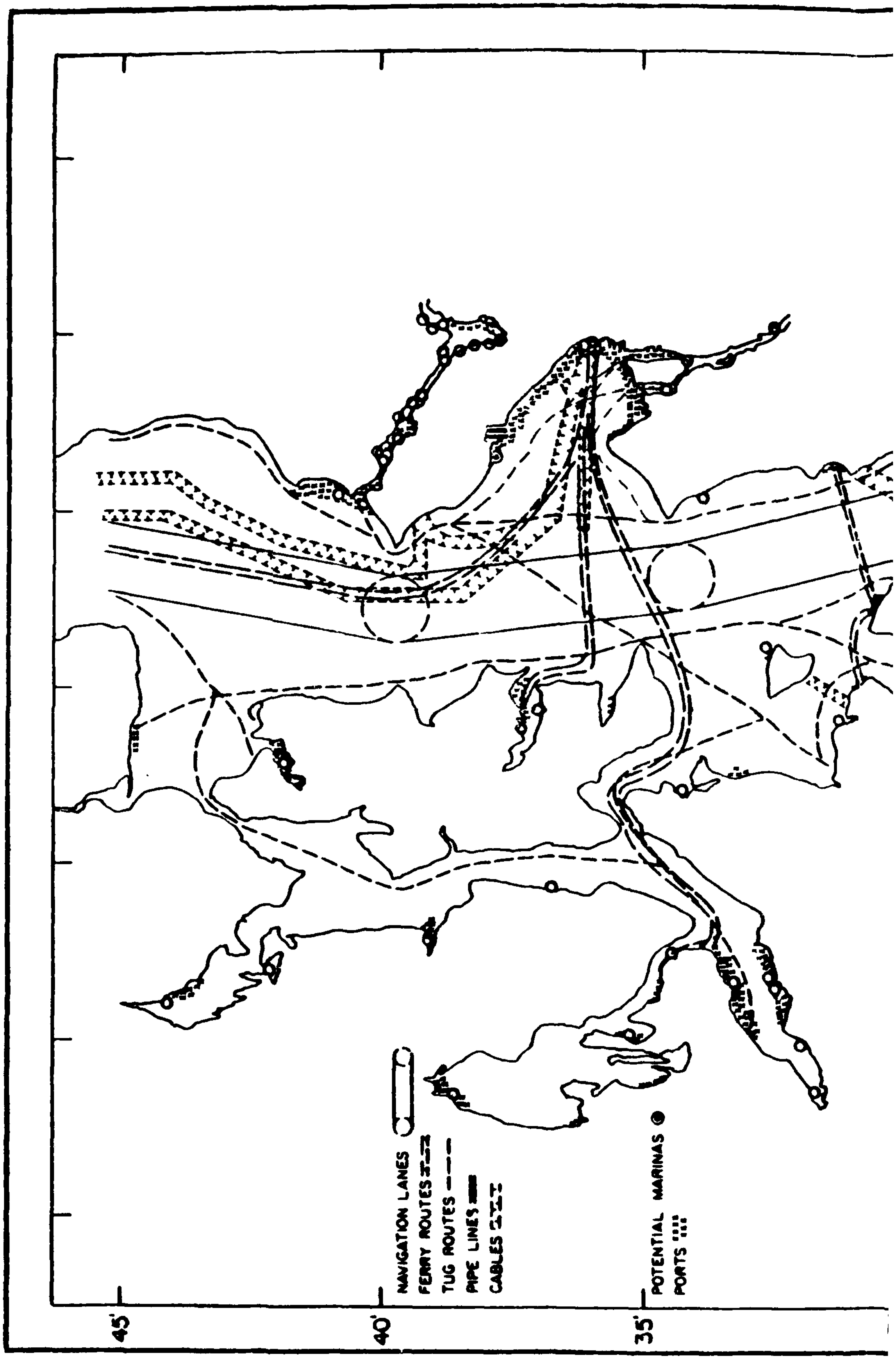

POLITICAL BOUNDARIES
SHORELINE MASTER PLANS
SHORELINE PARKS
TRIBAL FISHERIES
SEATTLE
KITSAP CO.
PIERCE CO.
KING CO.
TACOMA
0 1 2 3 4 N.M.
0 3000 6000 YARDS
47° 30'
25'
20'
45'
40'
35'
122°30'
15'

Figure B-2B


NAVIGATION LANES
FERRY ROUTES TUG ROUTES
PIPE LINES CABLES
POTENTIAL MARINAS PORTS
10'
05'
48°


48°
55'
50'
45'
NAVIGATION LANES
AREAS OF HIGH DENSITY TRAFFIC
UTILITIES
MARINAS O
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'


NAVIGATION LANES
FERRY ROUTES
TUG ROUTES
PIPE LINES
CABLES
POTENTIAL MARINAS
PORTS
45'
40'
35'

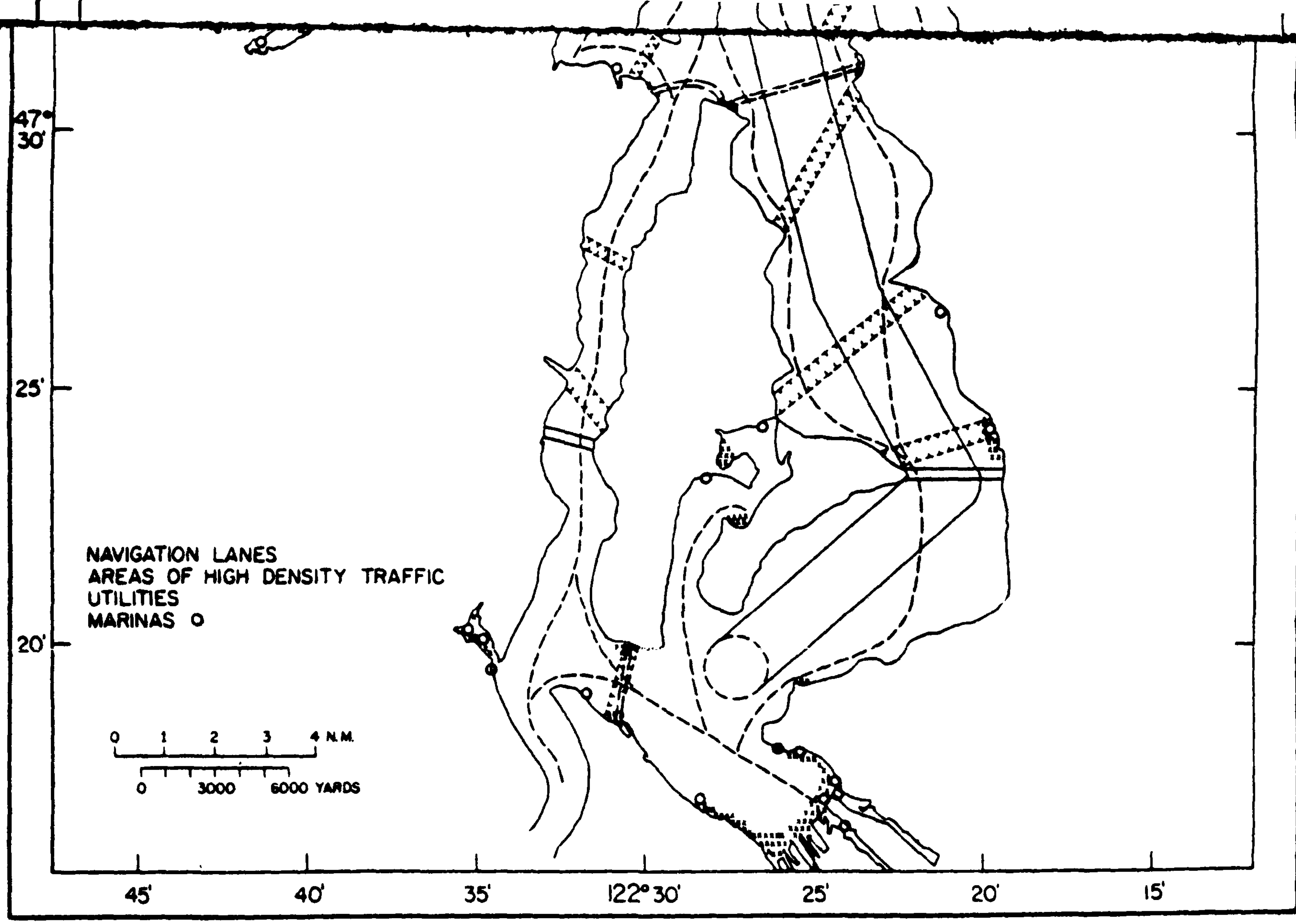
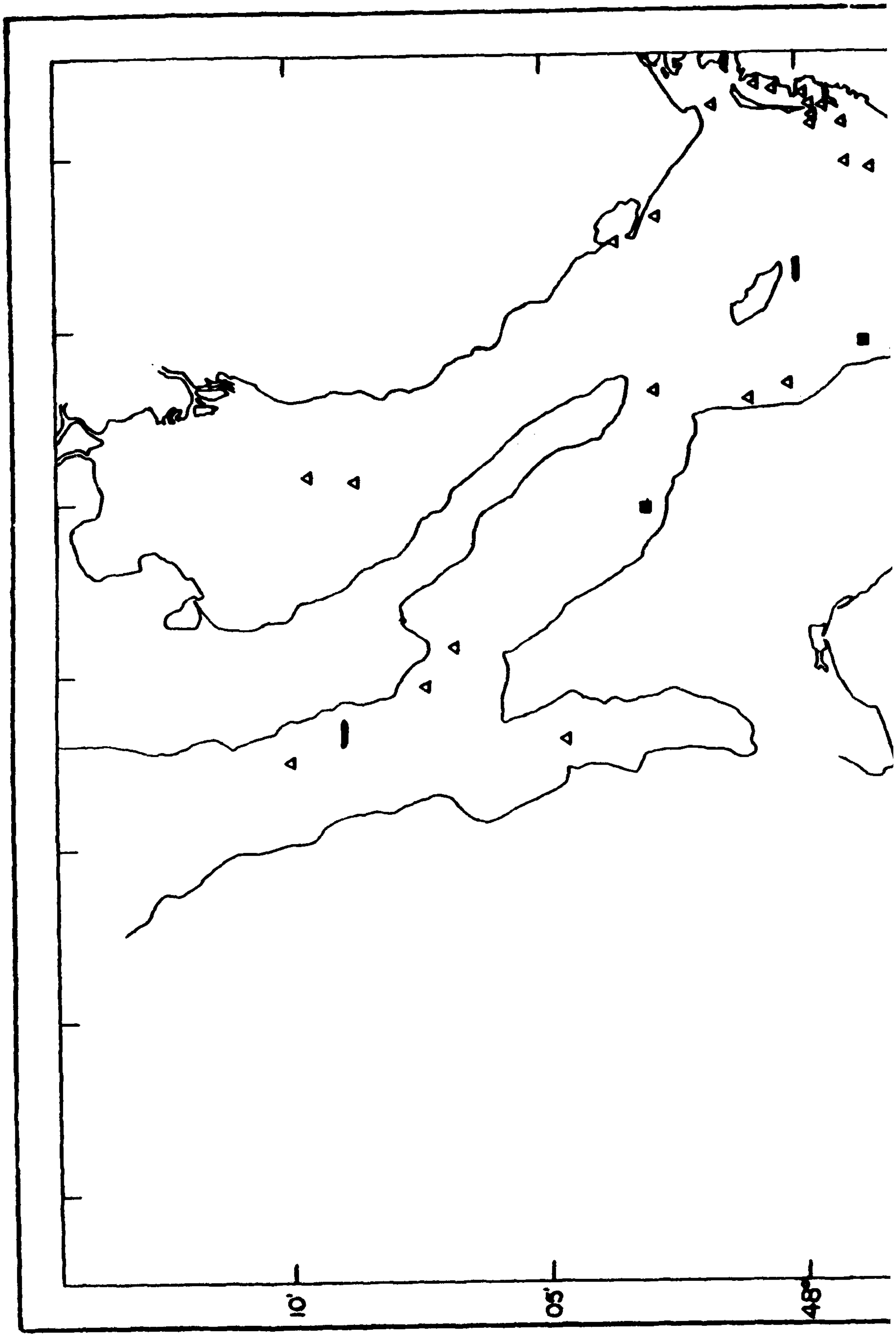

47° 30'
25'
20'
NAVIGATION LANES
AREAS OF HIGH DENSITY TRAFFIC
UTILITIES
MARINAS O
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122° 30'
25'
20'
15'

Figure B-3B


10'
05'
48°

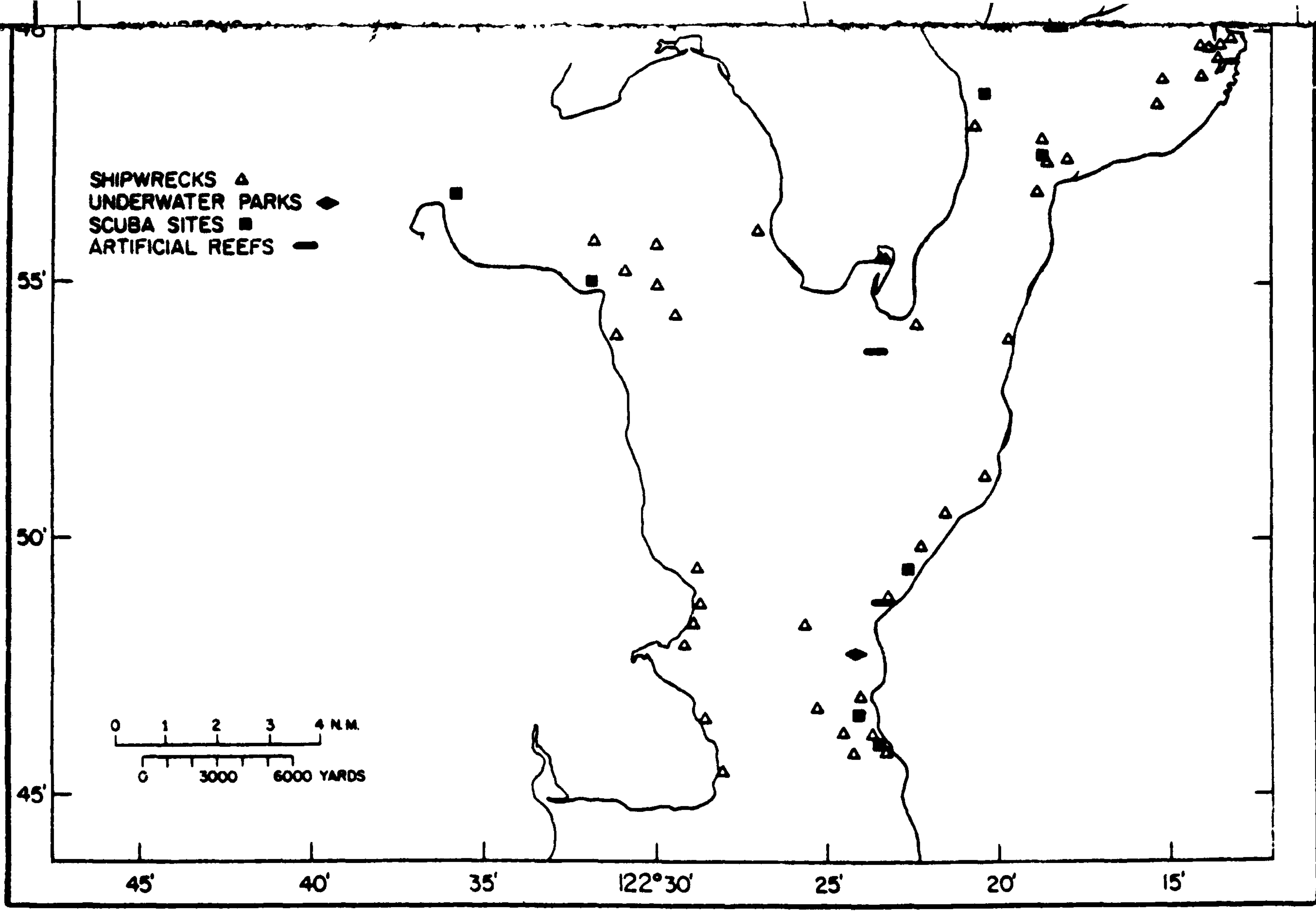
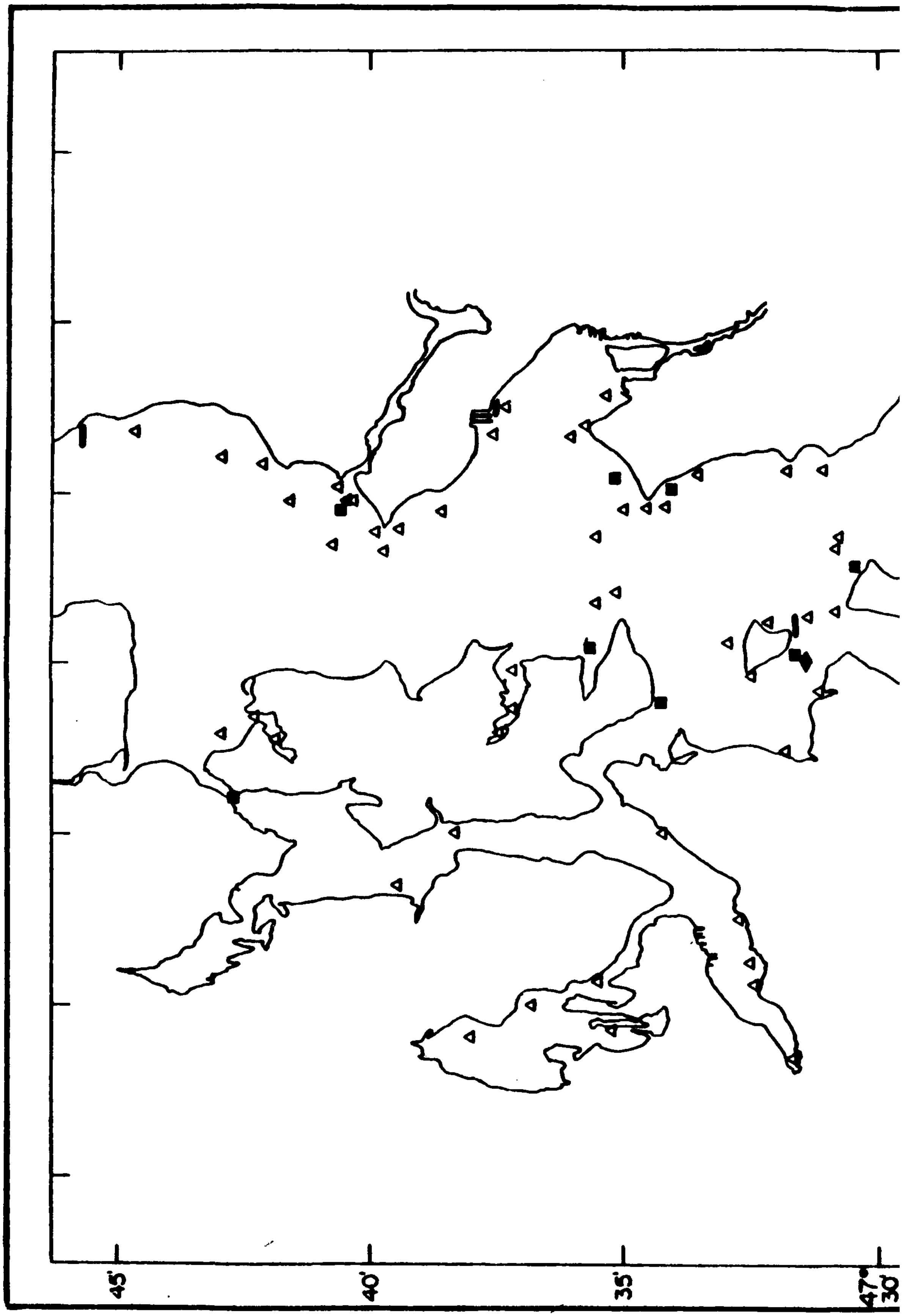
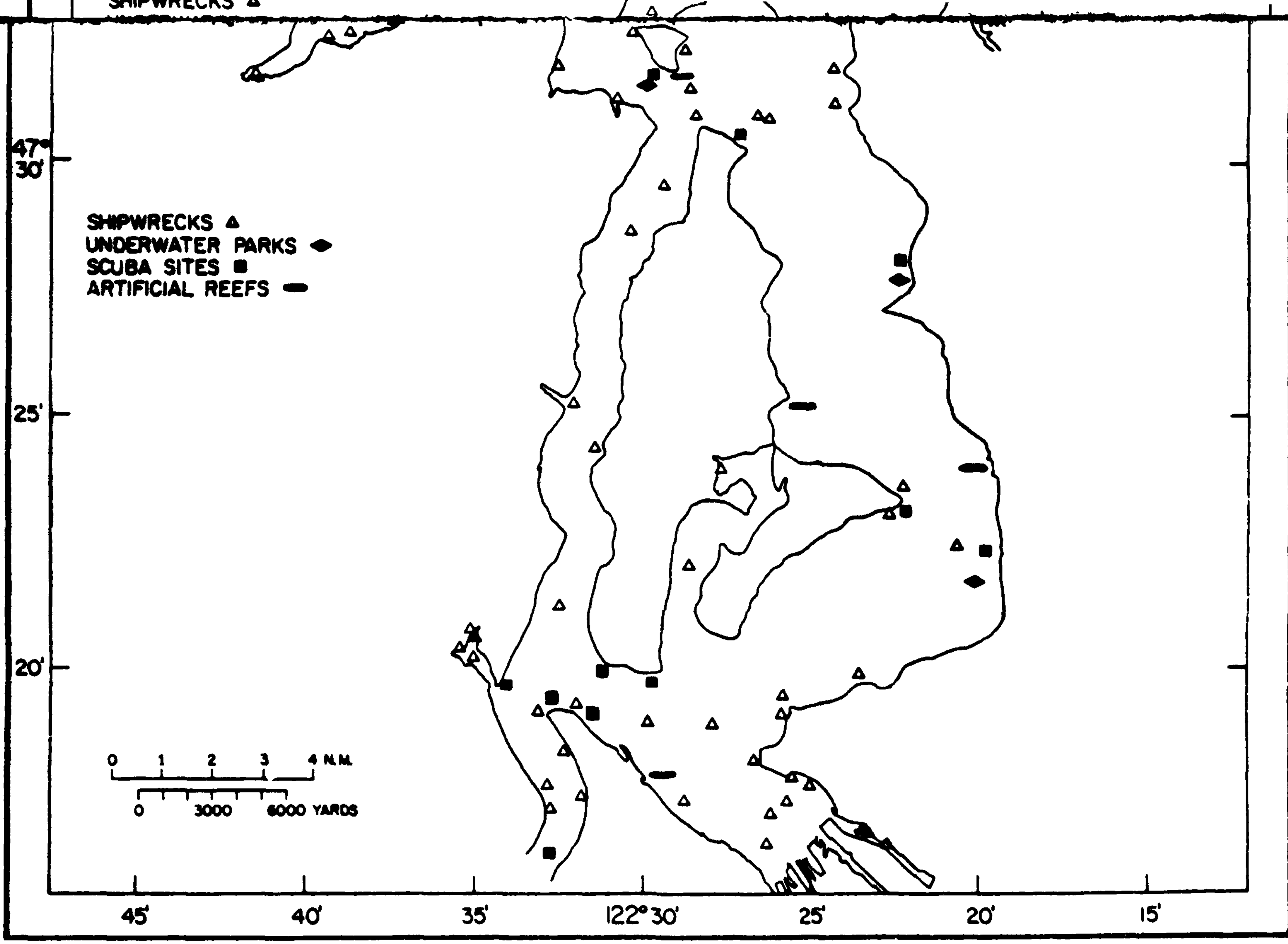

SHIPWRECKS
UNDERWATER PARKS
SCUBA SITES
ARTIFICIAL REEFS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
55'
50'
45'
45'
40'
35'
122°30'
25'
20'
15'

Figure B-4A


45'
40'
35'
47° 30'


SHIPWRECKS
UNDERWATER PARKS
SCUBA SITES
ARTIFICIAL REEFS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
47° 30'
25'
20'
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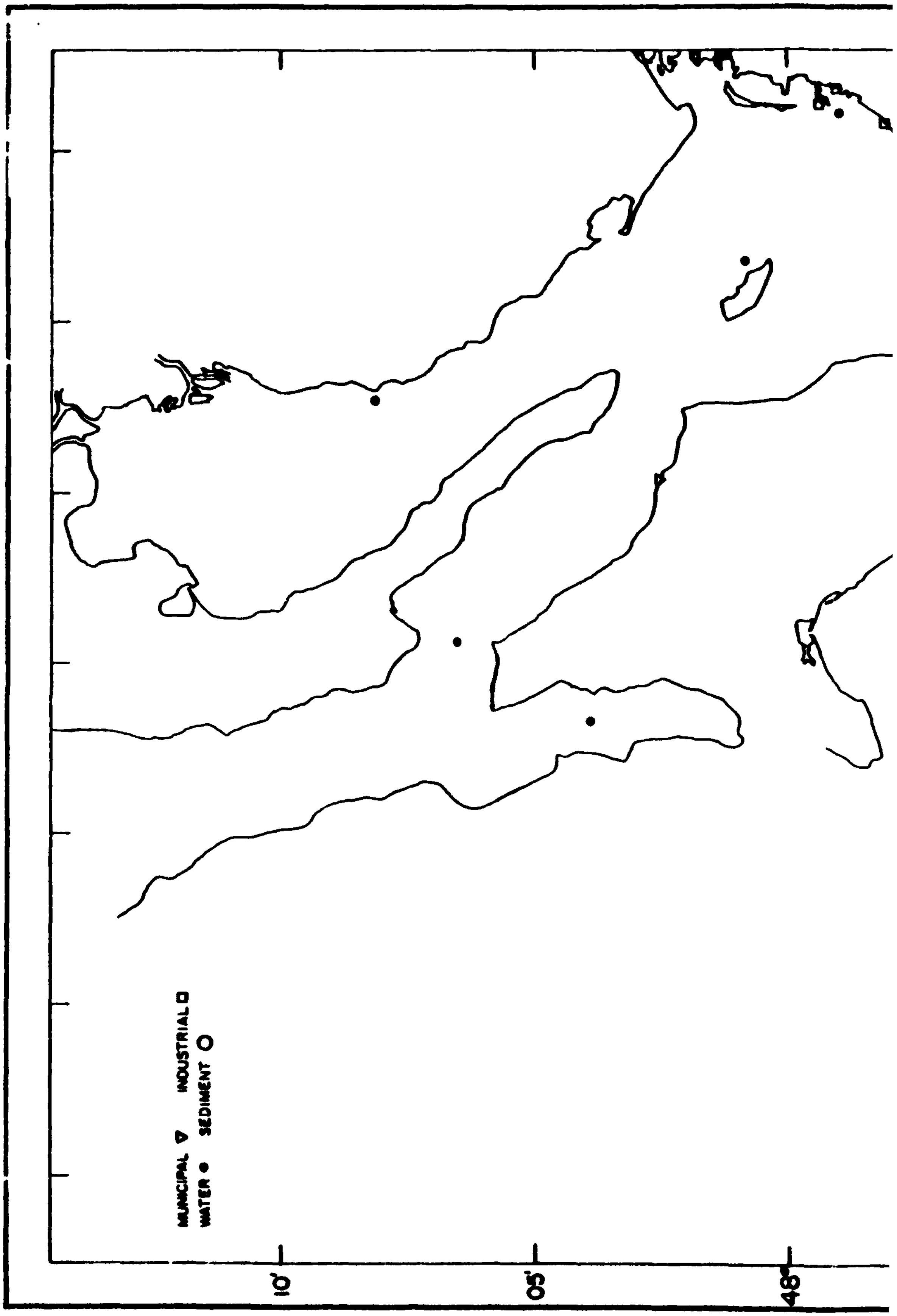
40'
35'
122° 30'
25'
20'
15'


MUNICIPAL ▽ INDUSTRIAL □
WATER ● SEDIMENT ○
10'
05'
48°

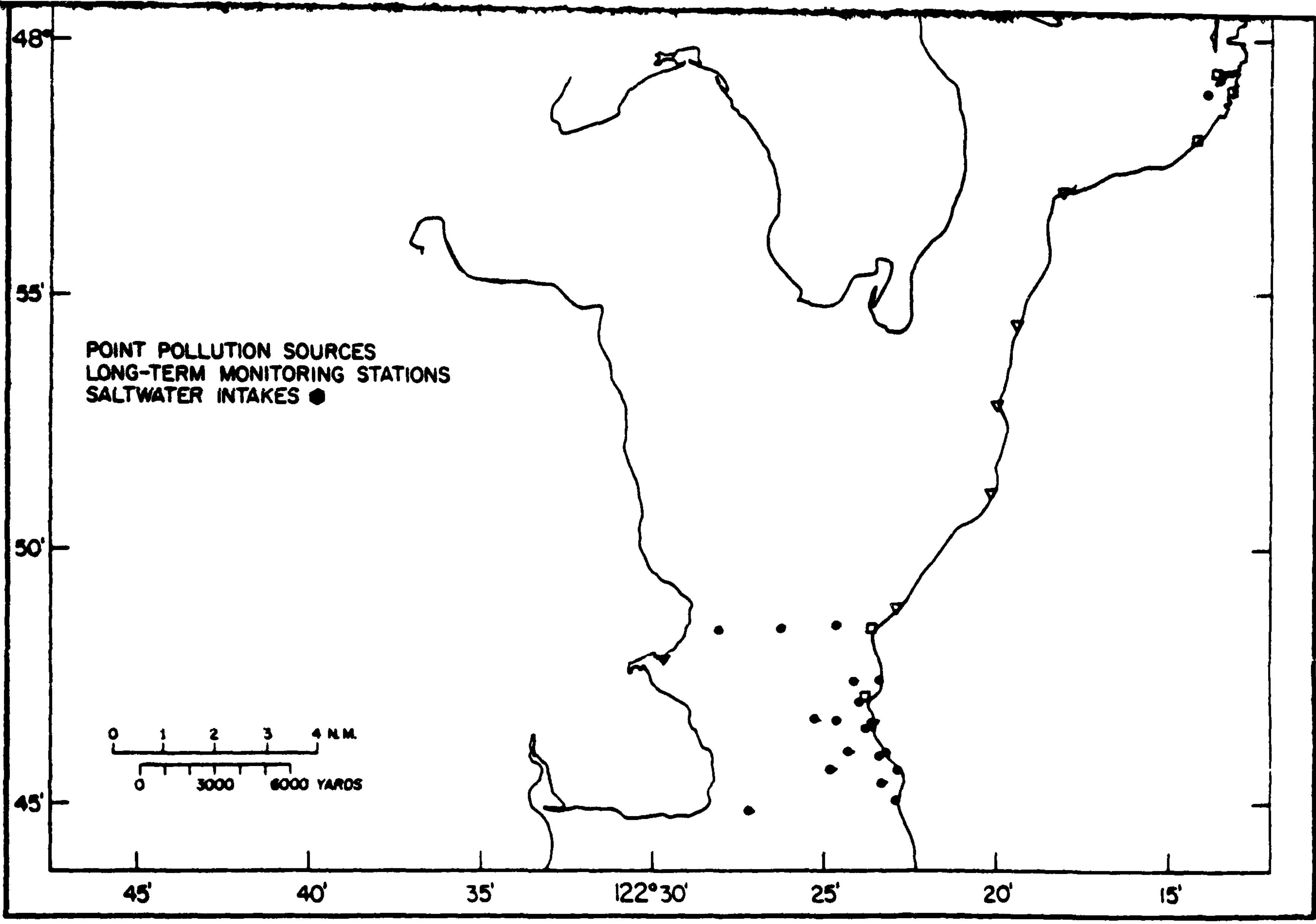
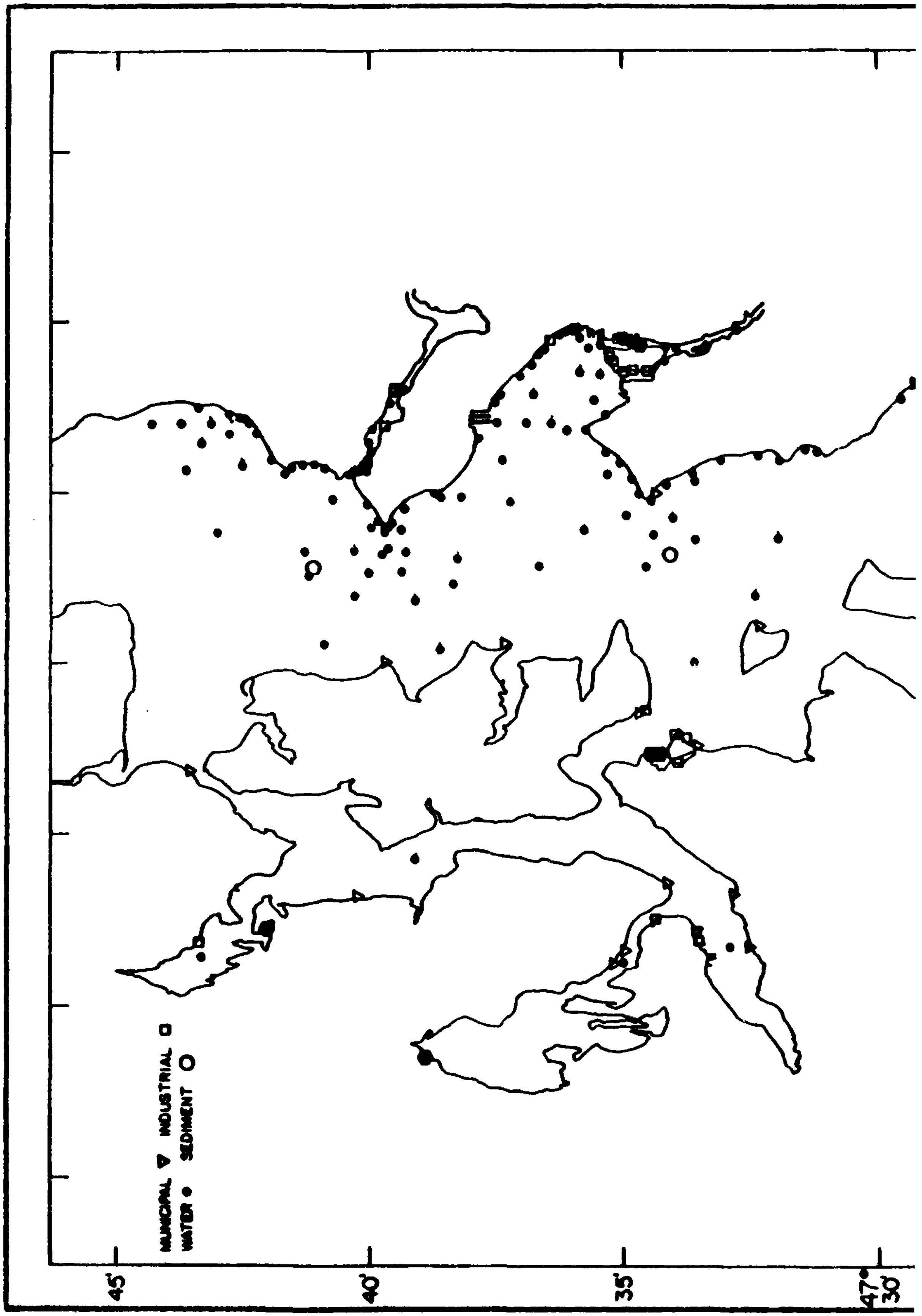

48°
55'
50'
45'
POINT POLLUTION SOURCES
LONG-TERM MONITORING STATIONS
SALTWATER INTAKES
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-5A


MUNICIPAL ▽ INDUSTRIAL □
WATER ● SEDIMENT ○
45'
40'
35'
47° 30'

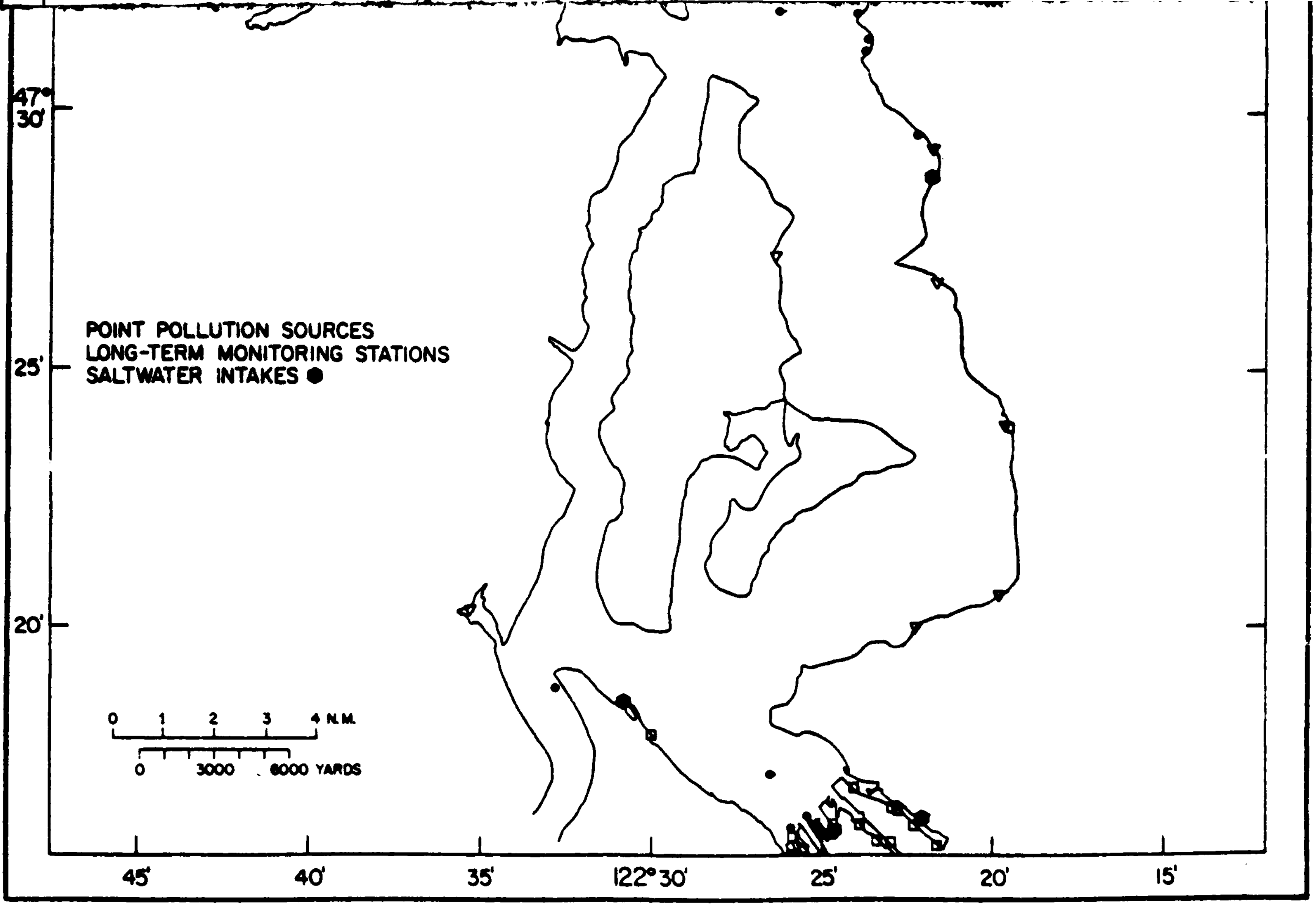

47°
30'
25'
20'
POINT POLLUTION SOURCES
LONG-TERM MONITORING STATIONS
SALTWATER INTAKES ●
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-5B

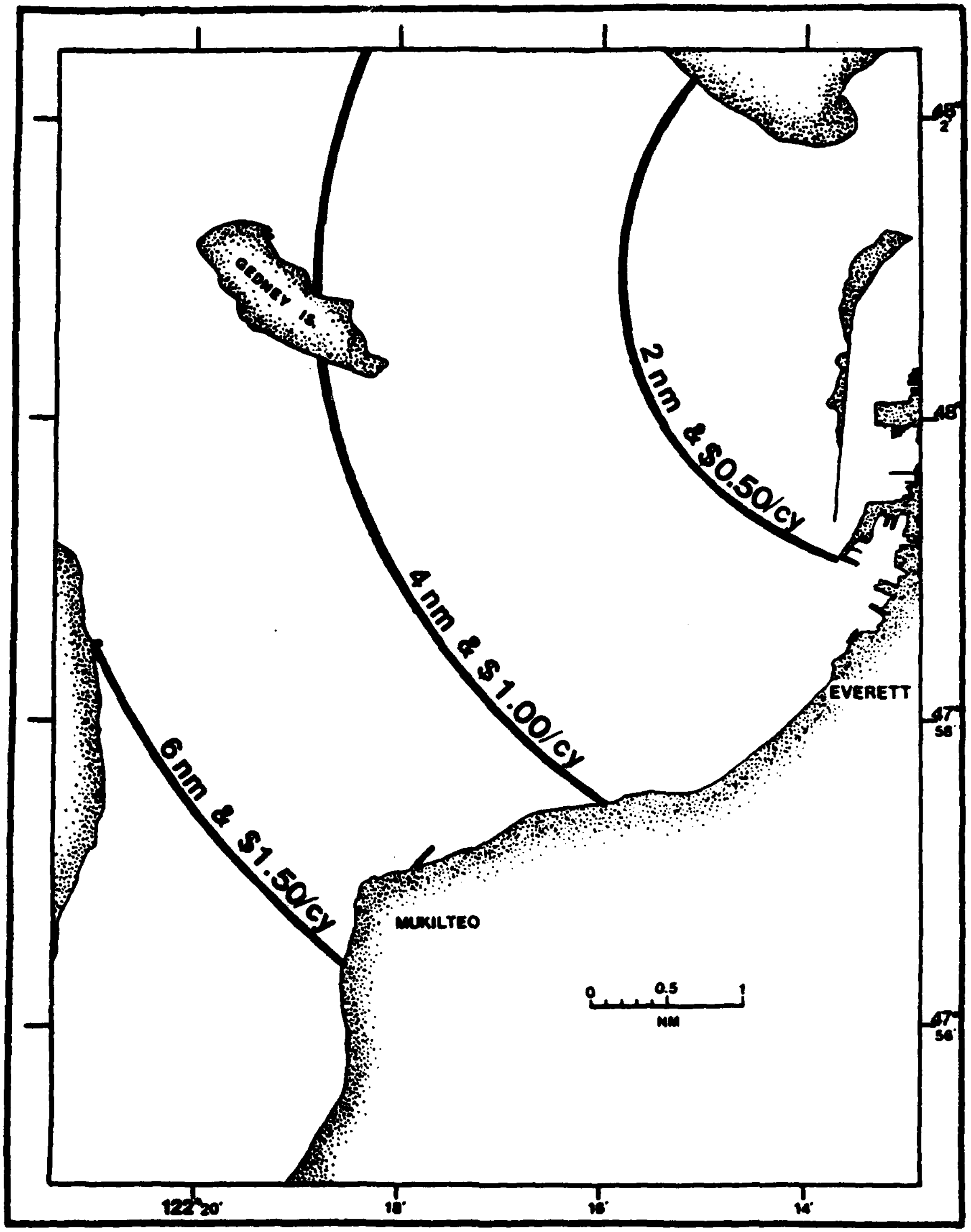

GEDNEY IS.
2 nm & $0.50/cy
4 nm & $1.00/cy
6 nm & $1.50/cy
EVERETT
MUKILTEO
0
0.5
1
NM
122°20'
18'
16'
14'

Figure B-6A

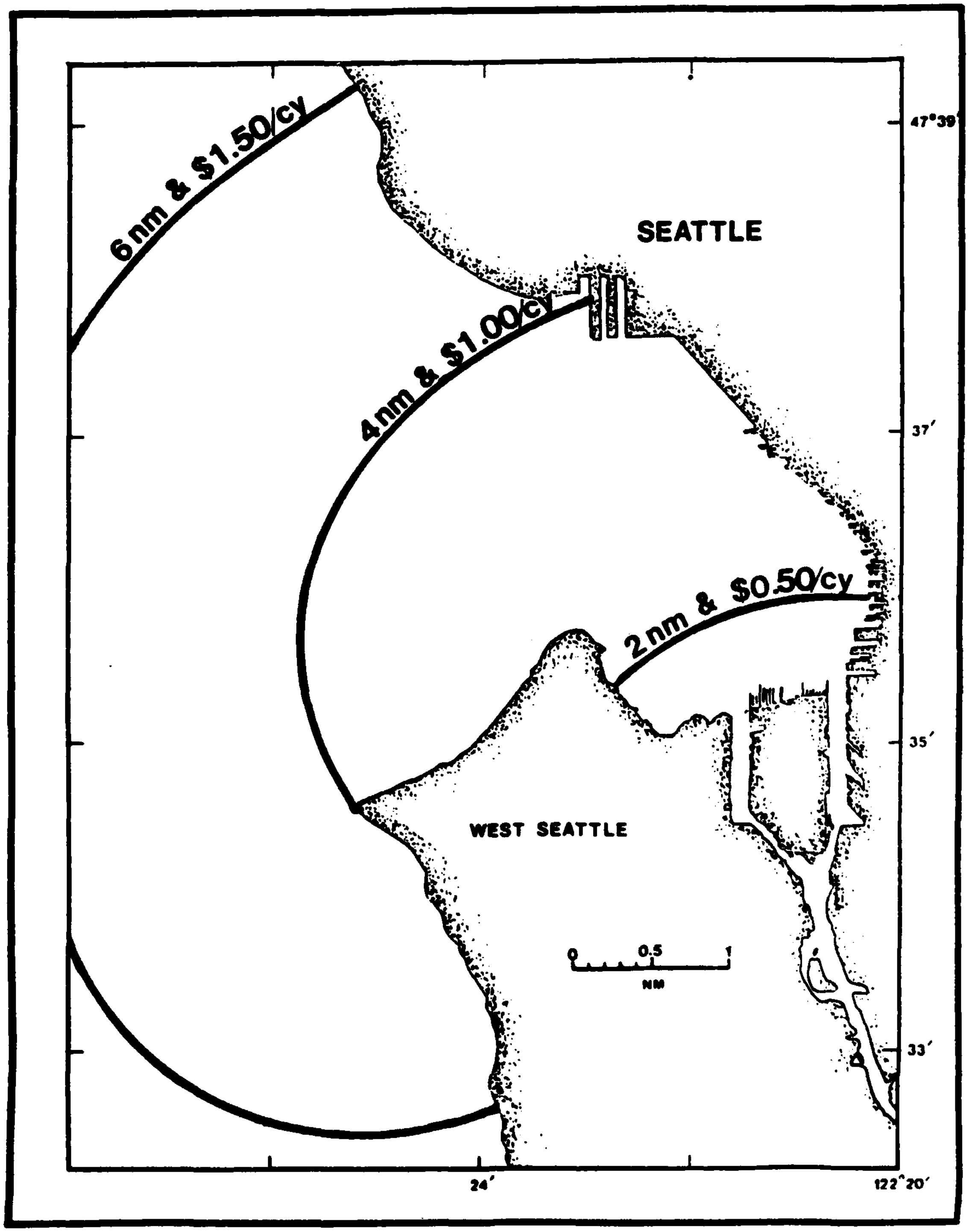

6 nm & $1.50/cy
4 nm & $1.00/cy
2 nm & $0.50/cy
SEATTLE
WEST SEATTLE
47°39'
37'
35'
33'
24'
122°20'
0
0.5
1
NM

Figure B-6B

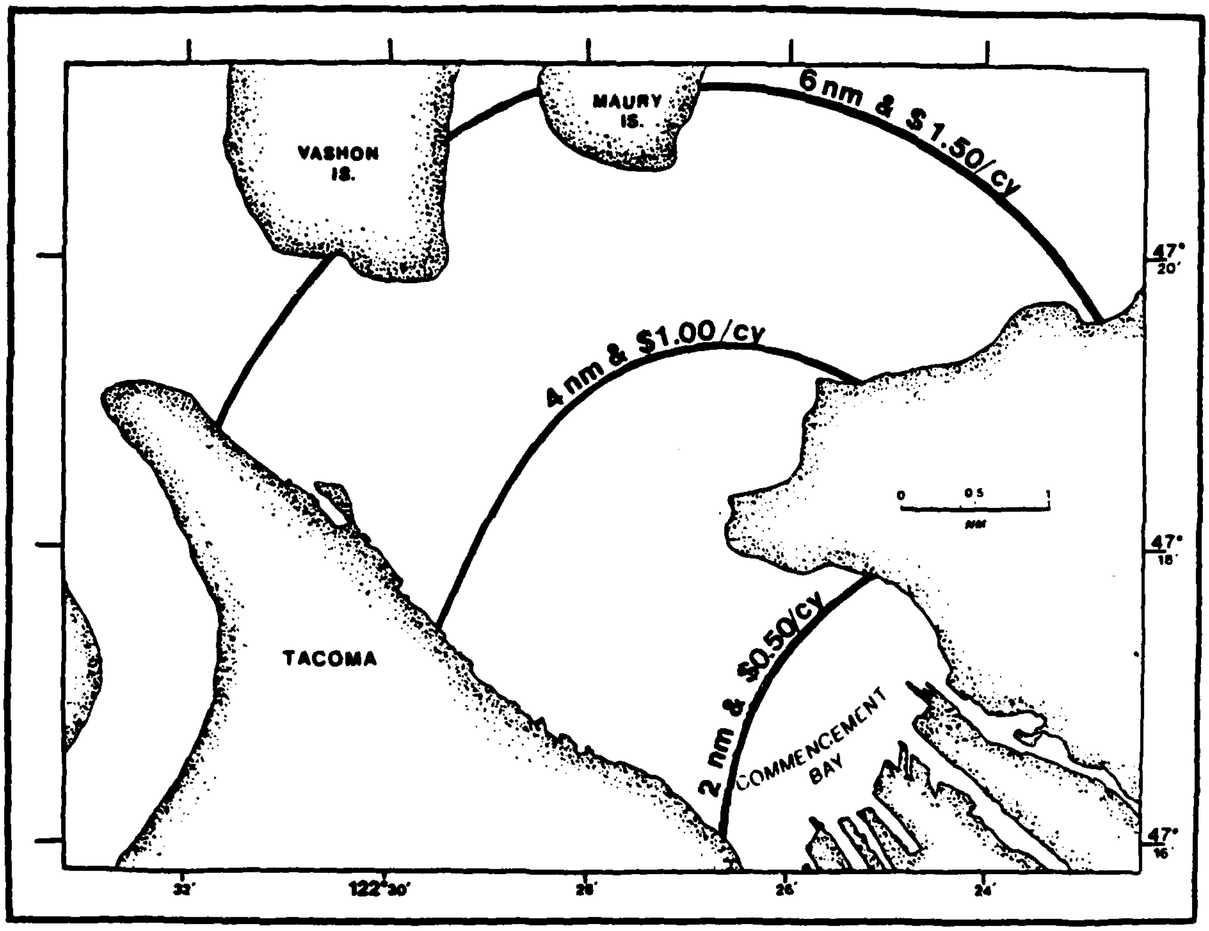
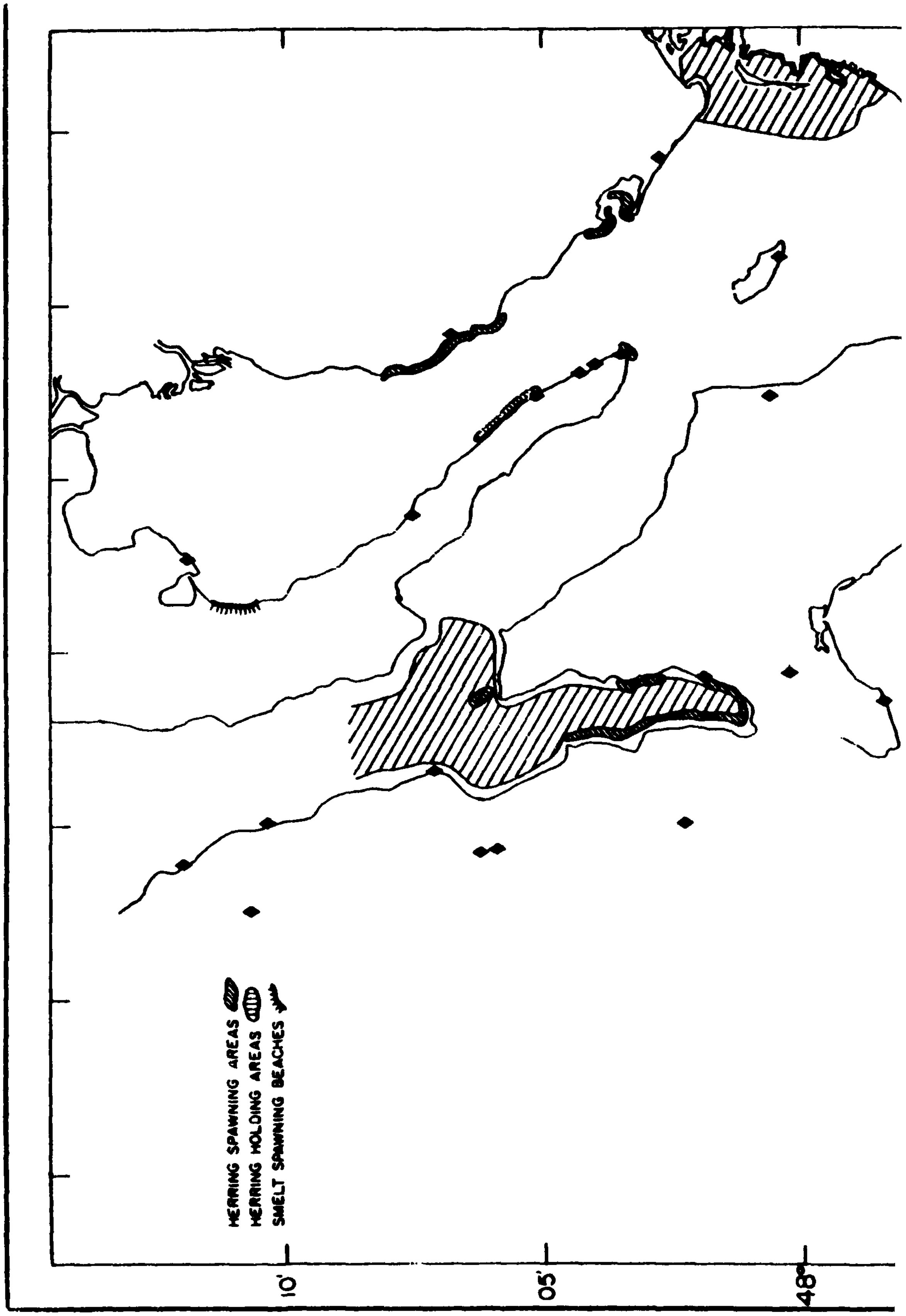

VASHON IS.
MAURY IS.
6 nm & $1.50/cy
4 nm & $1.00/cy
2 nm & $0.50/cy
TACOMA
COMMENCEMENT BAY
47° 20'
47° 18'
47° 16'
32'
122°30'
28'
26'
24'

Figure B-6C


HERRING SPAWNING AREAS
HERRING HOLDING AREAS
SMELT SPAWNING BEACHES
10'
05'
48°

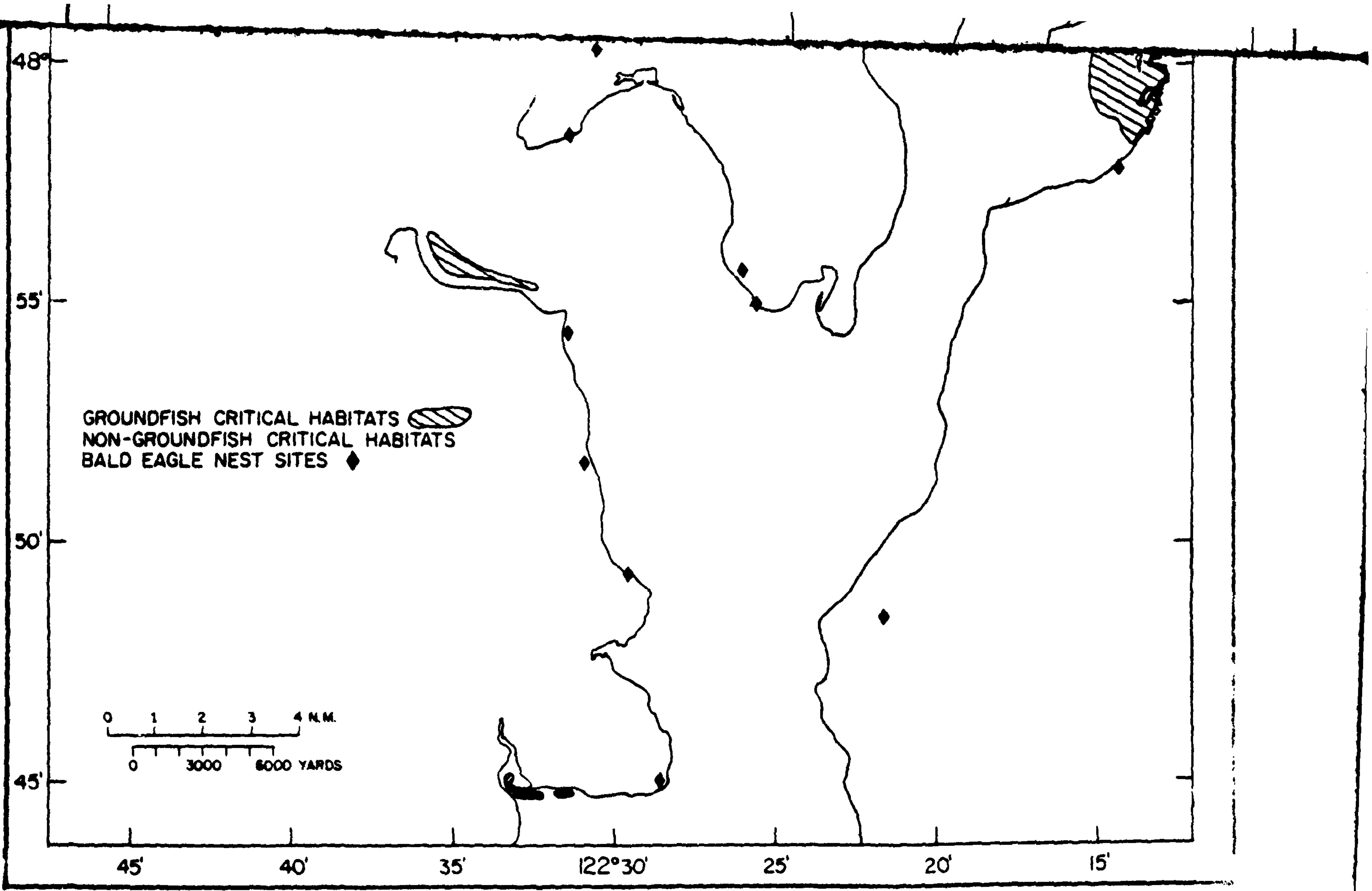
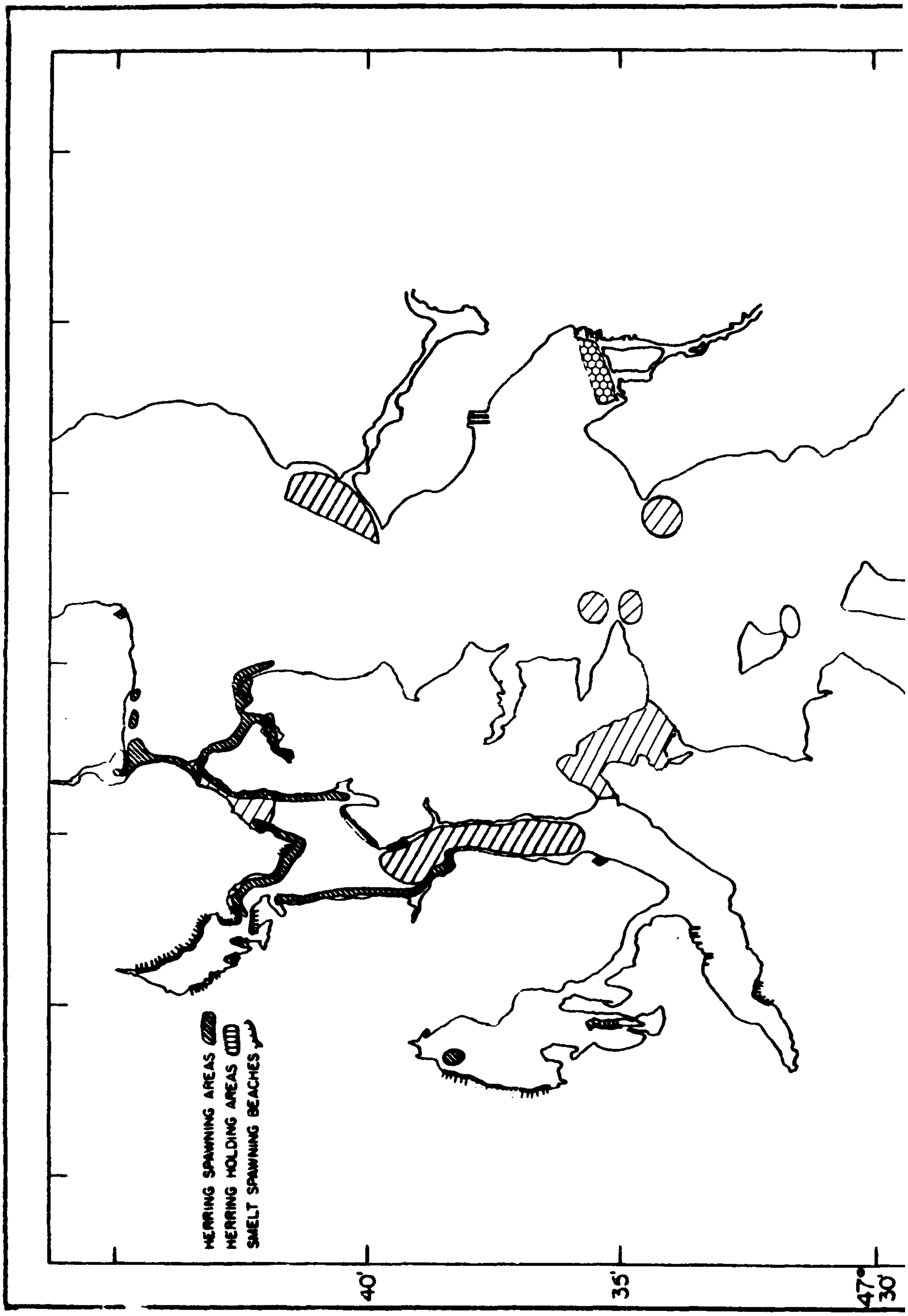

48°
55'
50'
45'
GROUNDFISH CRITICAL HABITATS
NON-GROUNDFISH CRITICAL HABITATS
BALD EAGLE NEST SITES
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-7A


HERRING SPAWNING AREAS
HERRING HOLDING AREAS
SMELT SPAWNING BEACHES
40'
35'
47° 30'

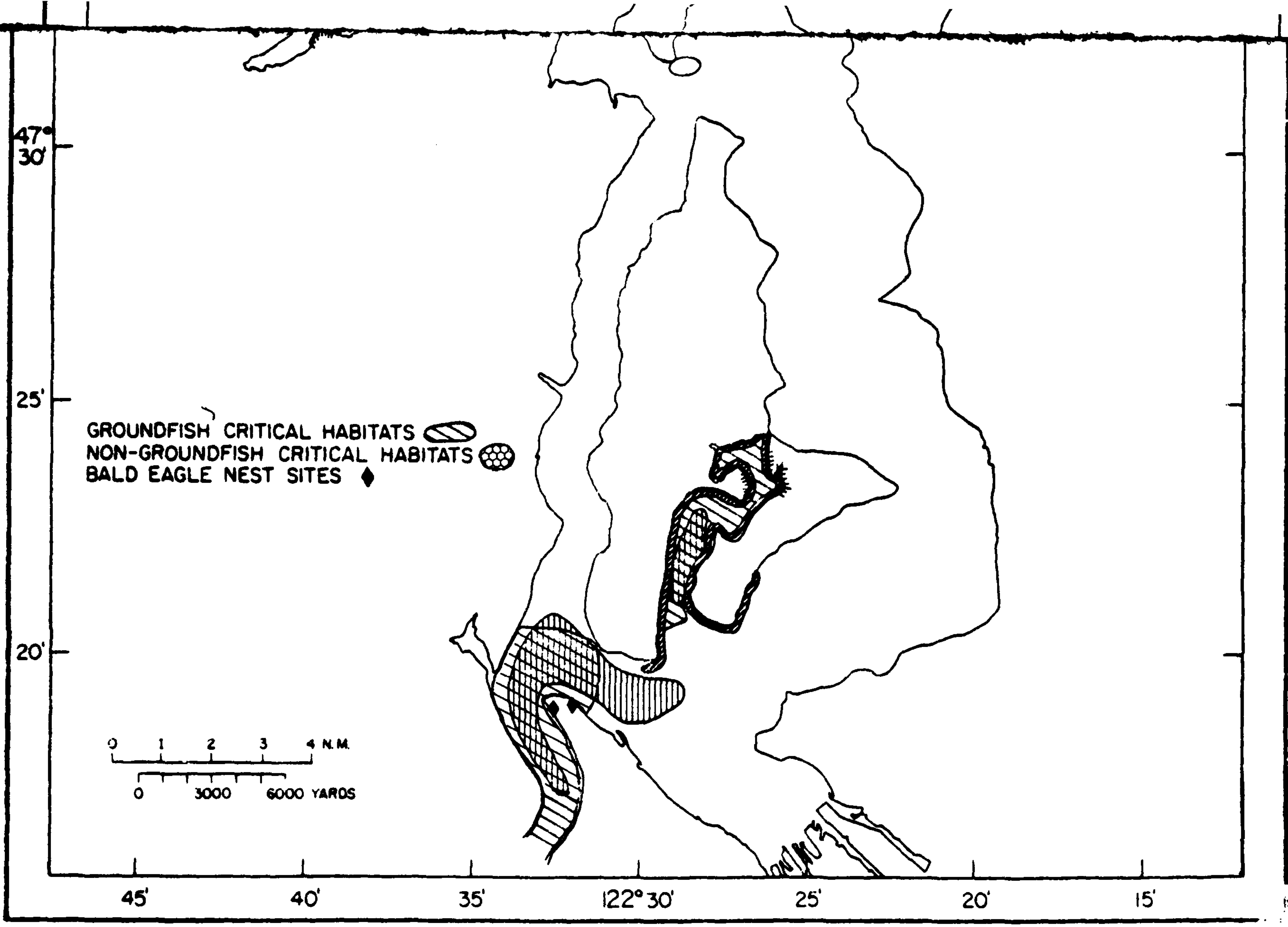
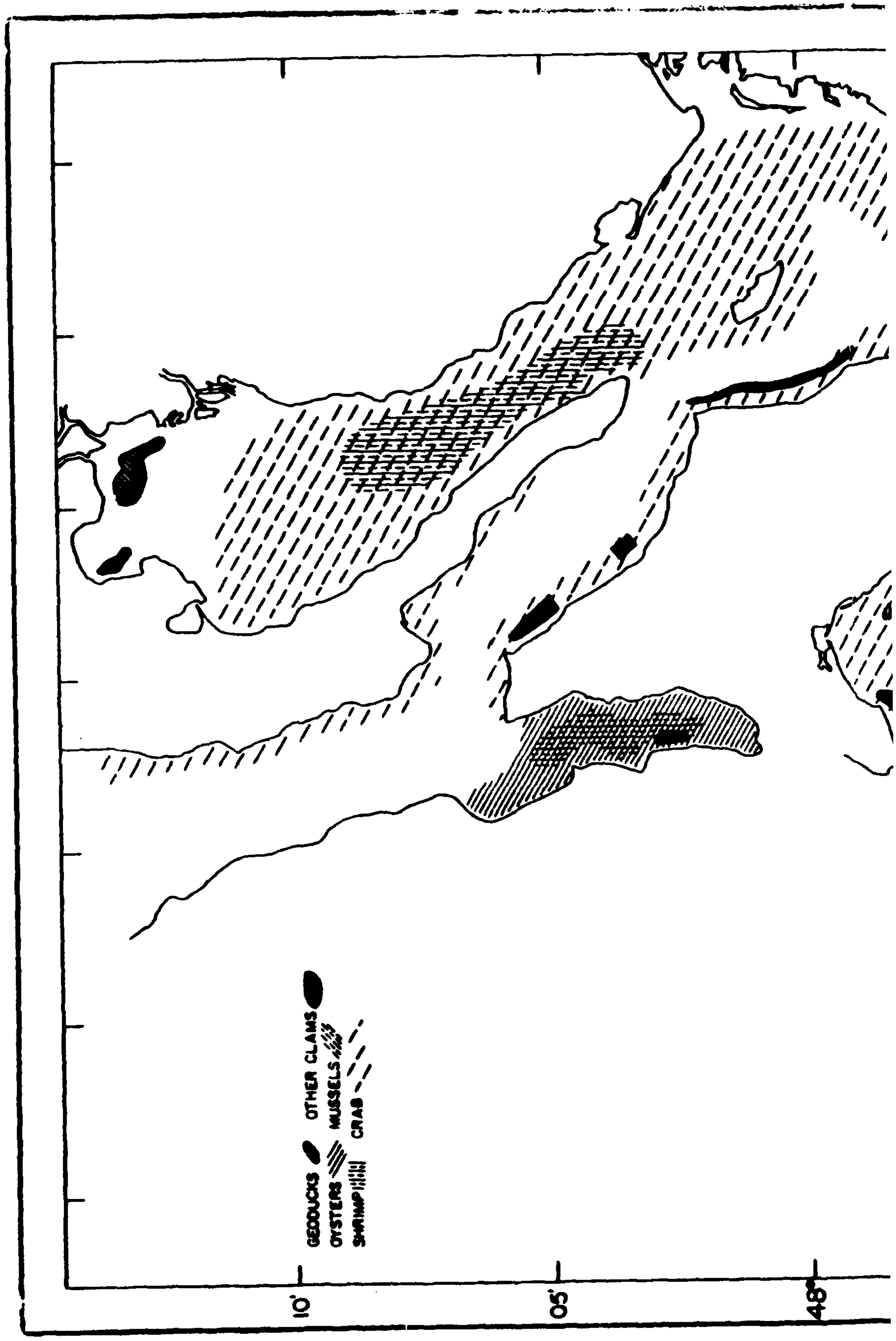

47°
30'
25'
20'
GROUNDFISH CRITICAL HABITATS
NON-GROUNDFISH CRITICAL HABITATS
BALD EAGLE NEST SITES
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-7B


GEODUCKS
OTHER CLAMS
OYSTERS
MUSSELS
SHRIMP
CRAB
10'
05'
48°

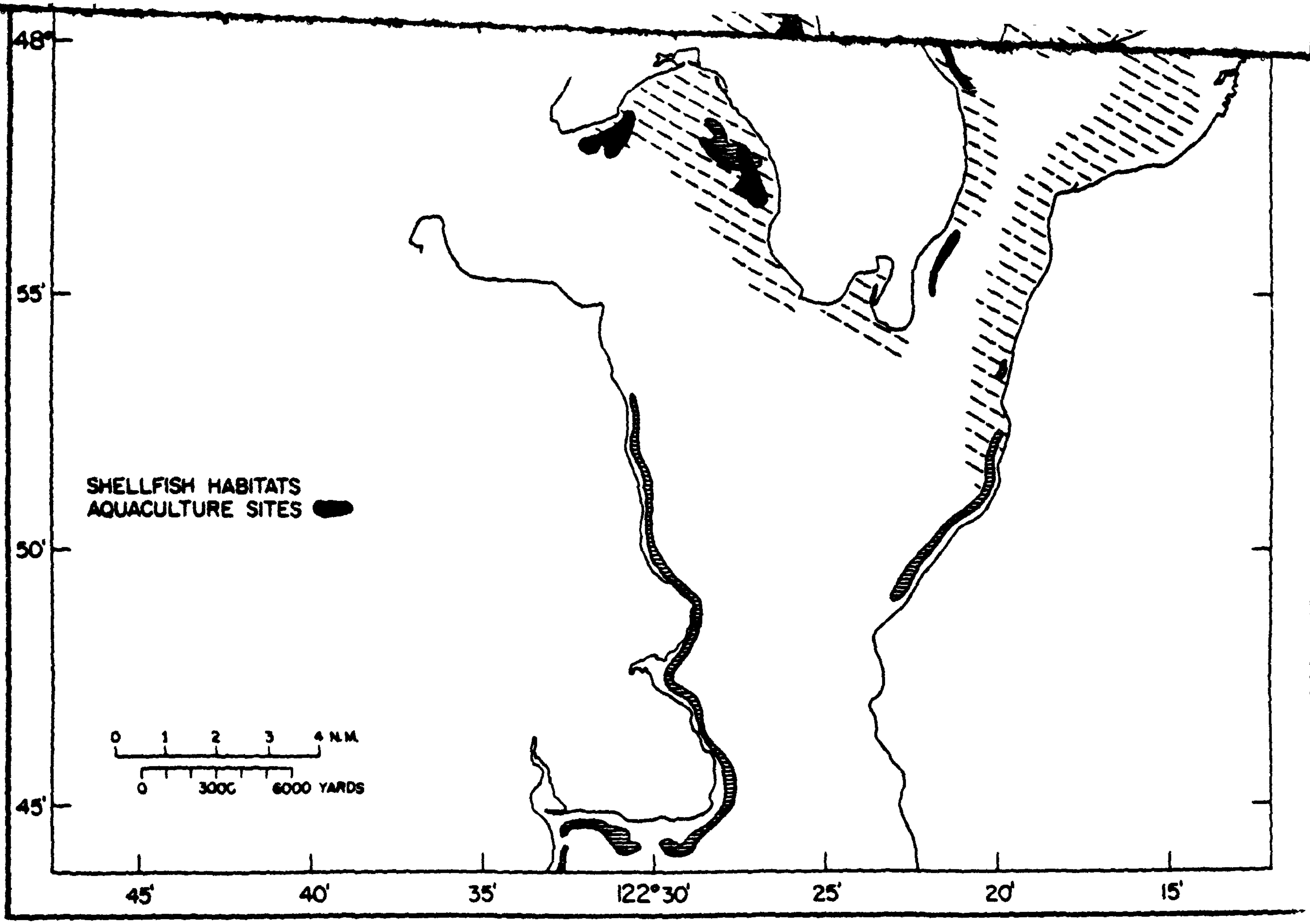
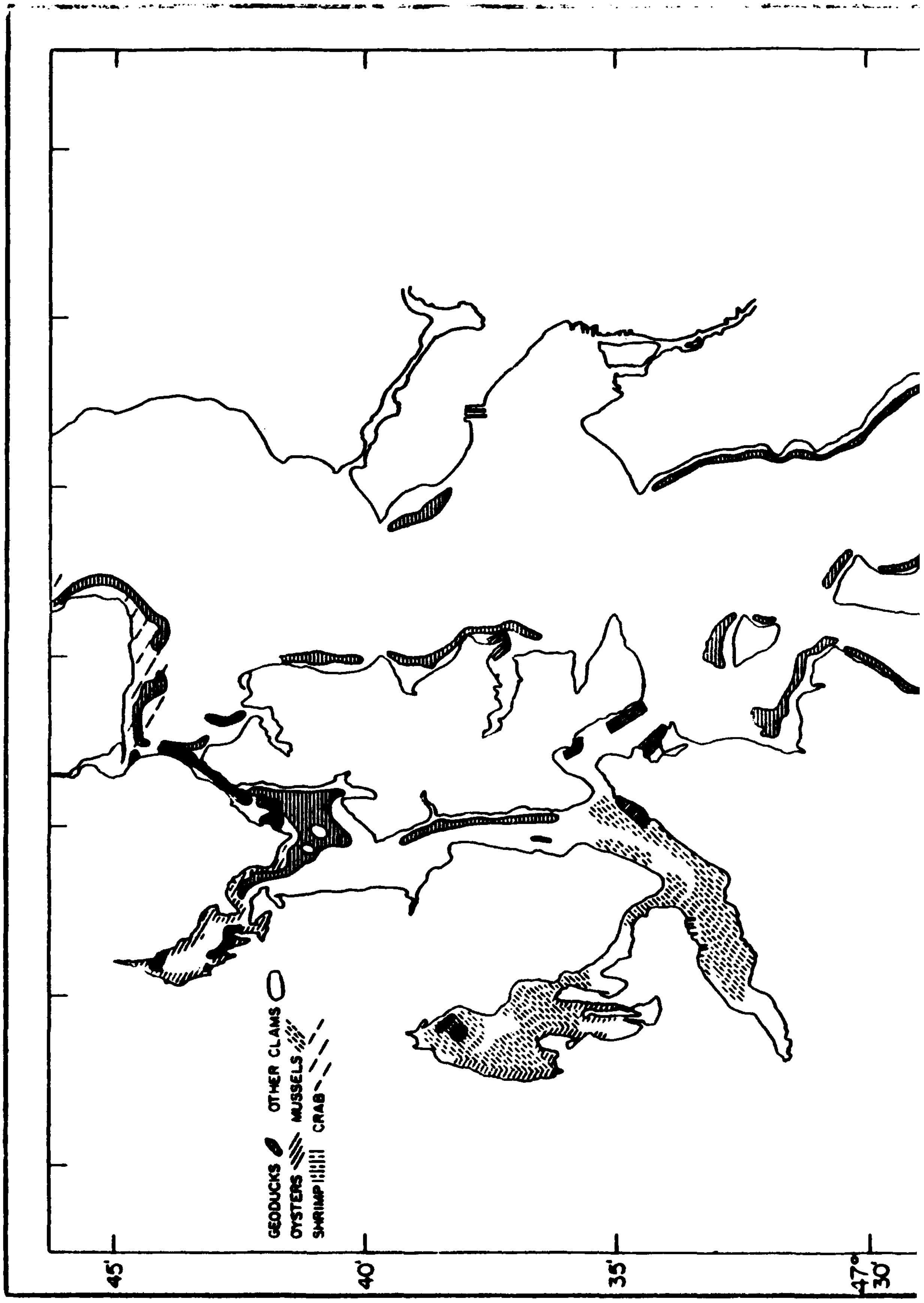

48°
55'
50'
45'
SHELLFISH HABITATS
AQUACULTURE SITES
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-8A


GEODUCKS
OYSTERS
SHRIMP
OTHER CLAMS
MUSSELS
CRAB
45'
40'
35'
47° 30'

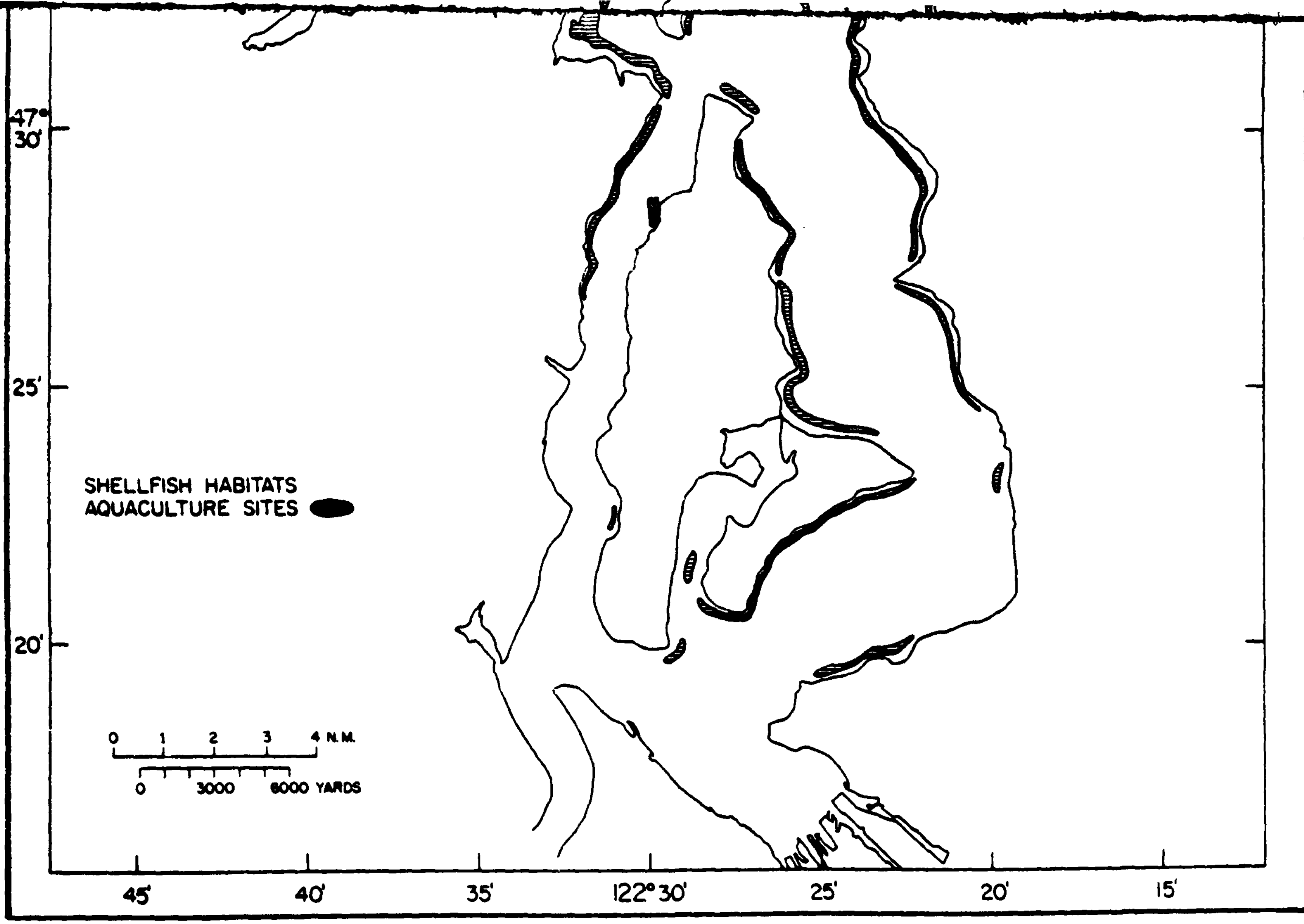
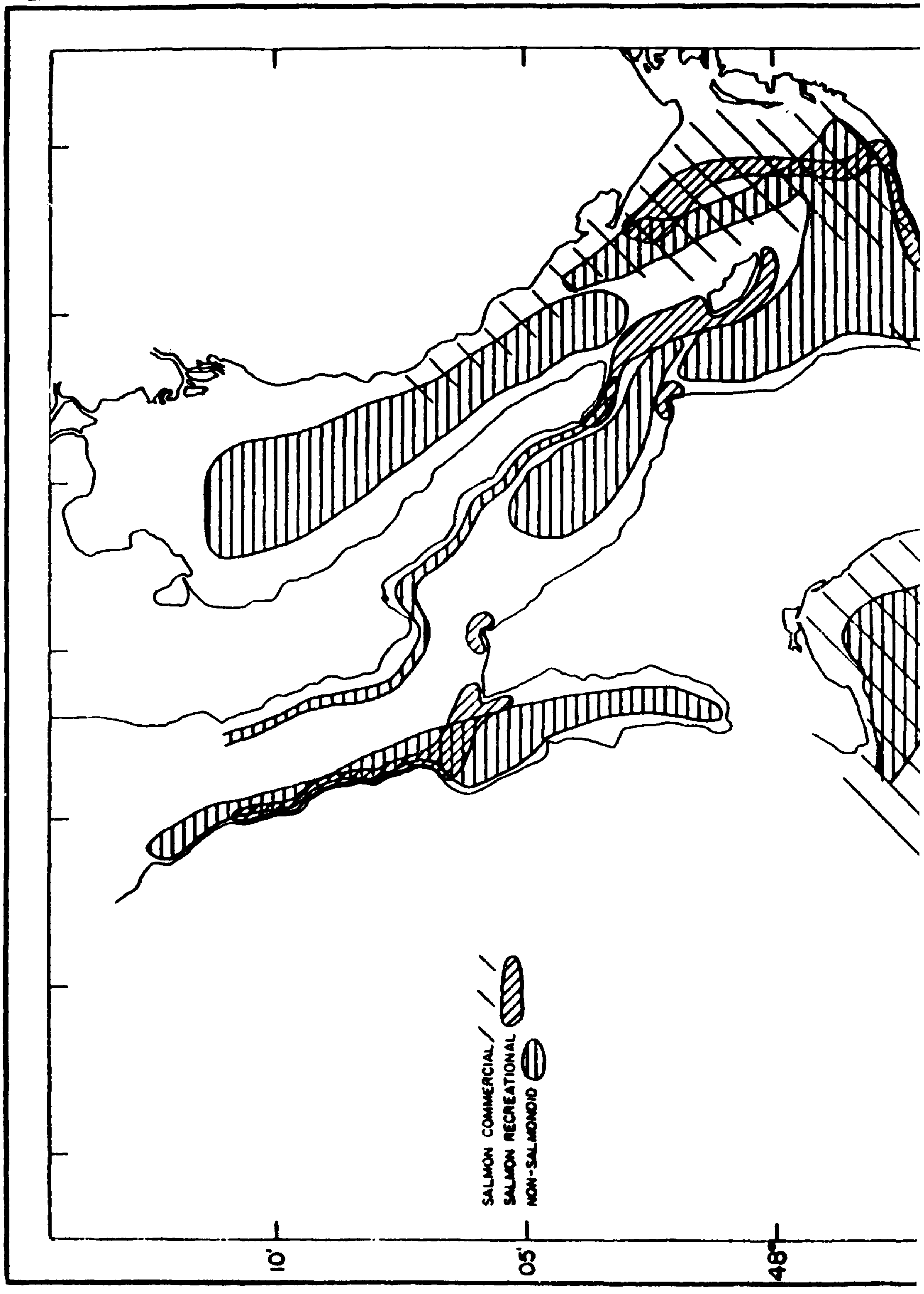

47° 30'
25'
20'
SHELLFISH HABITATS
AQUACULTURE SITES
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122° 30'
25'
20'
15'

Figure B-8B


SALMON COMMERCIAL
SALMON RECREATIONAL
NON-SALMONOID
10'
05'
48°

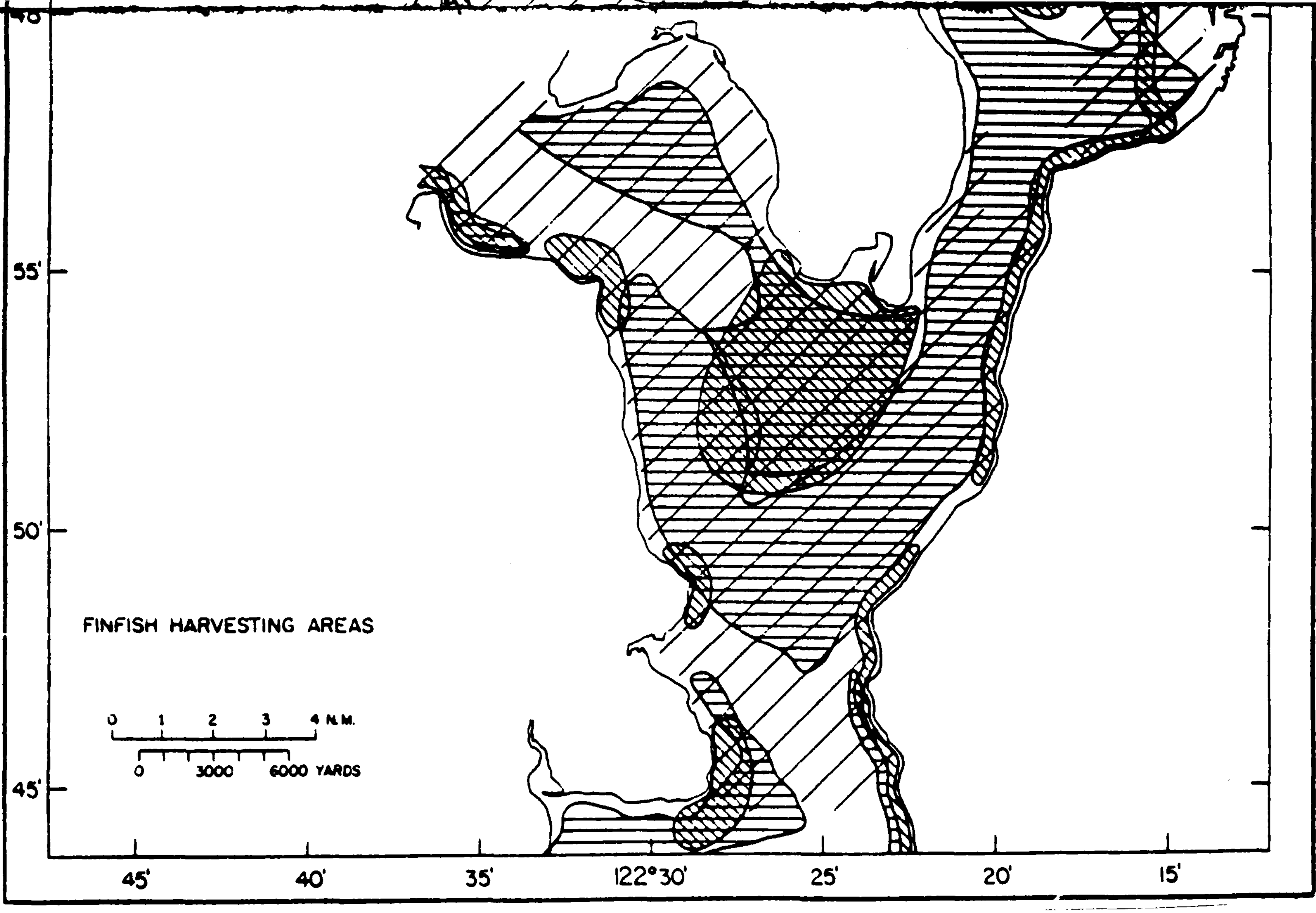
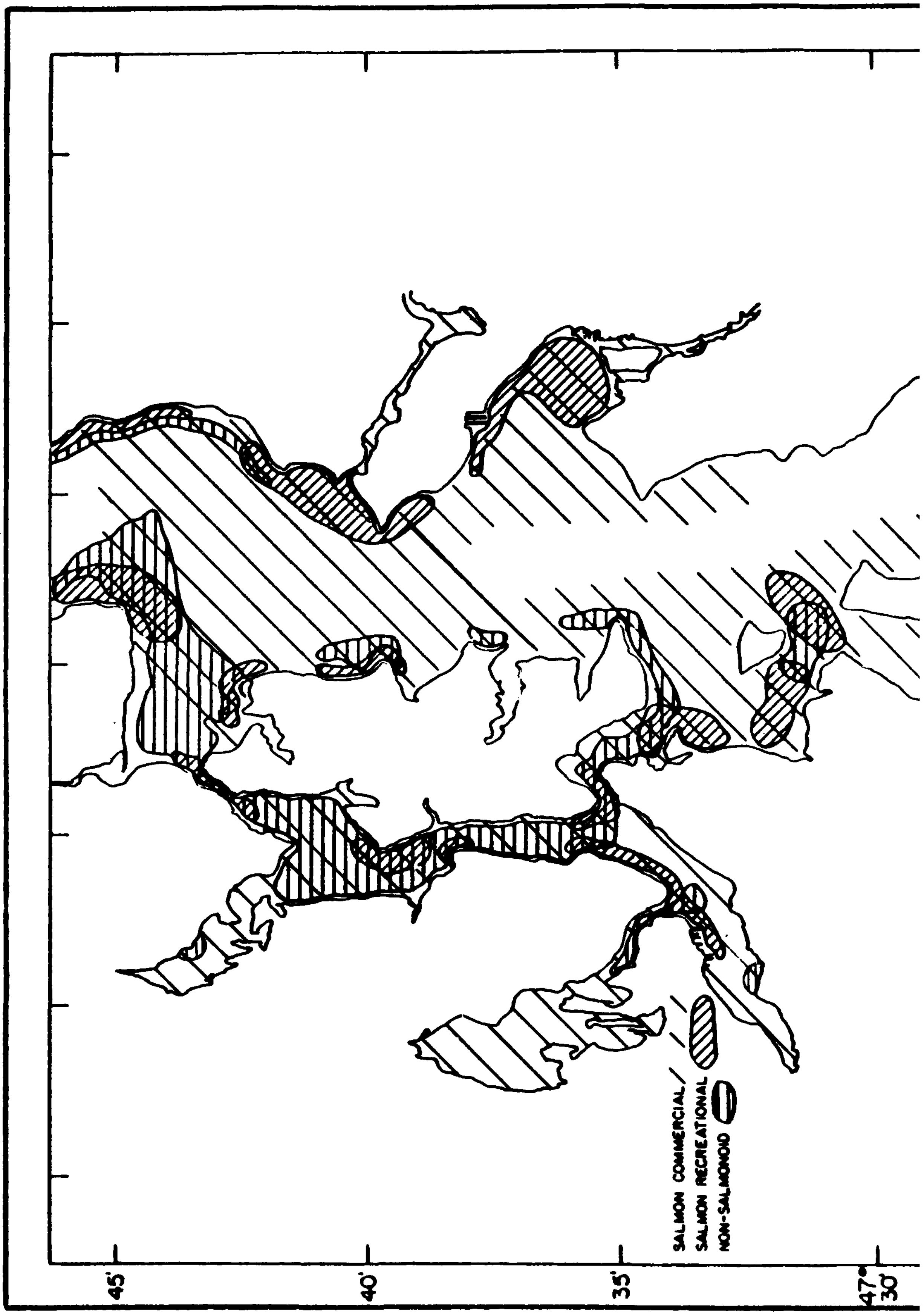

FINFISH HARVESTING AREAS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
55'
50'
45'
45'
40'
35'
122°30'
25'
20'
15'

Figure B-9A



SALMON COMMERCIAL
SALMON RECREATIONAL
NON-SALMONOID
45'
40'
35'
47° 30'

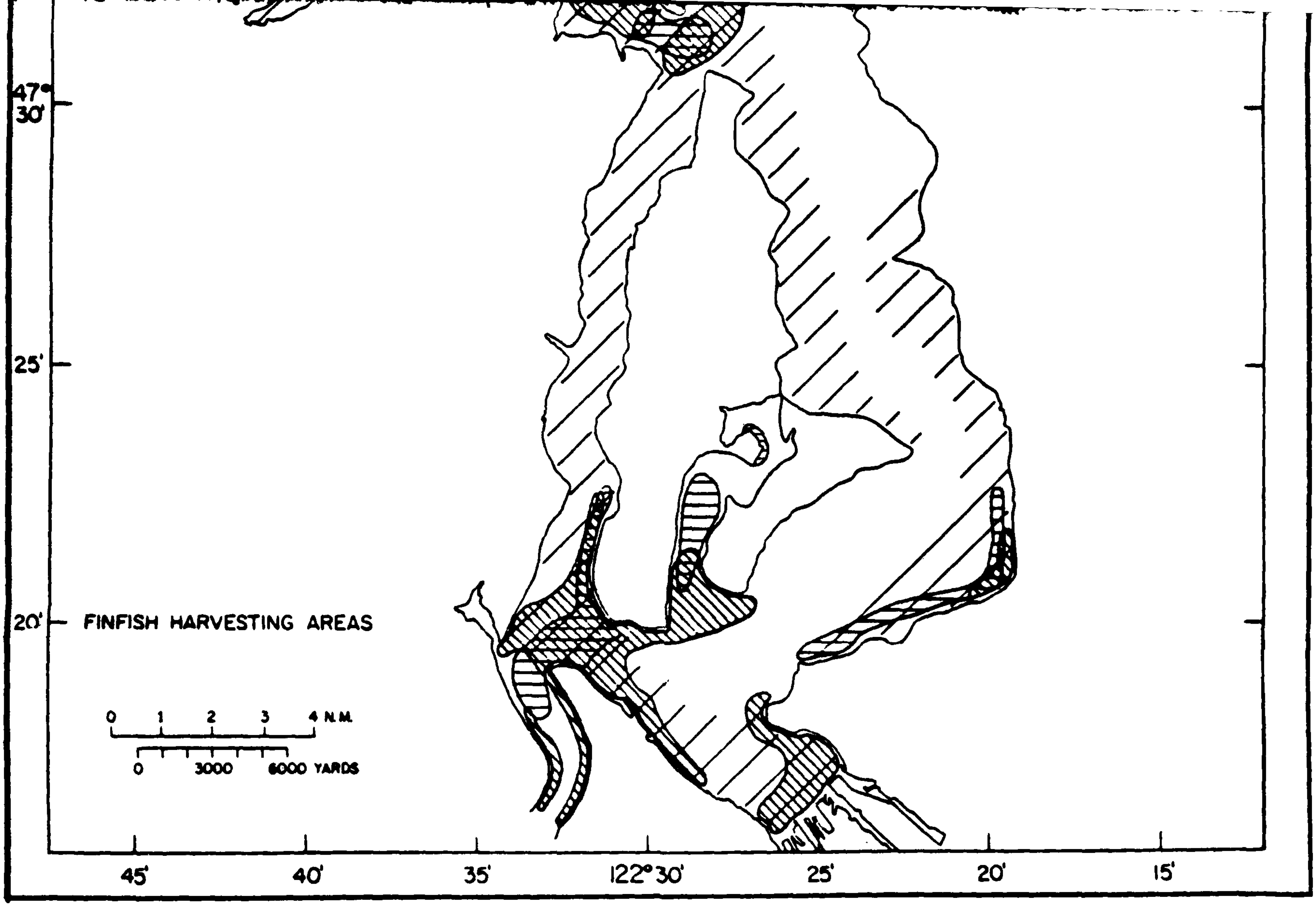
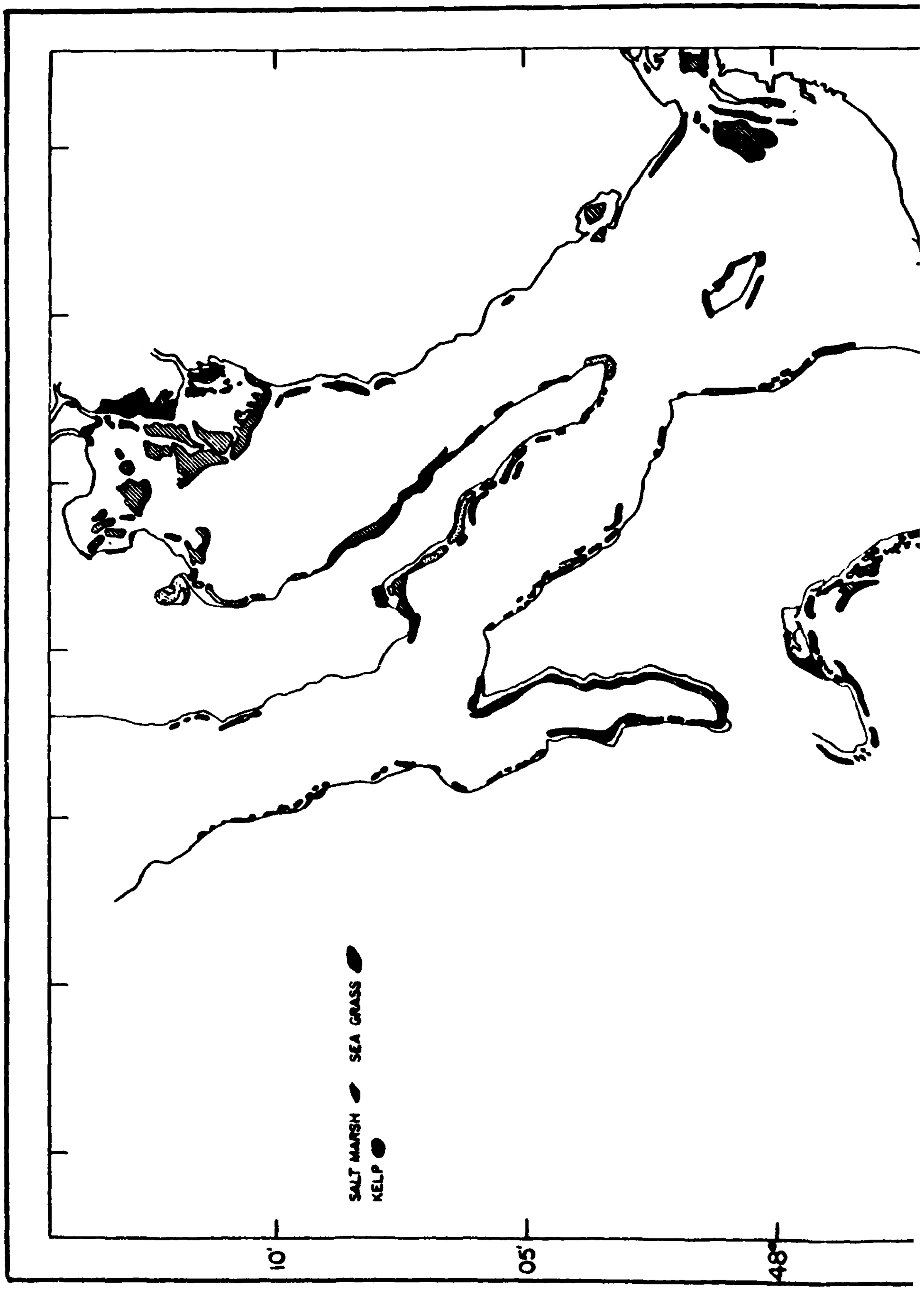

47° 30'
25'
20'
FINFISH HARVESTING AREAS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-9B


SALT MARSH
SEA GRASS
KELP
10'
05'
48°

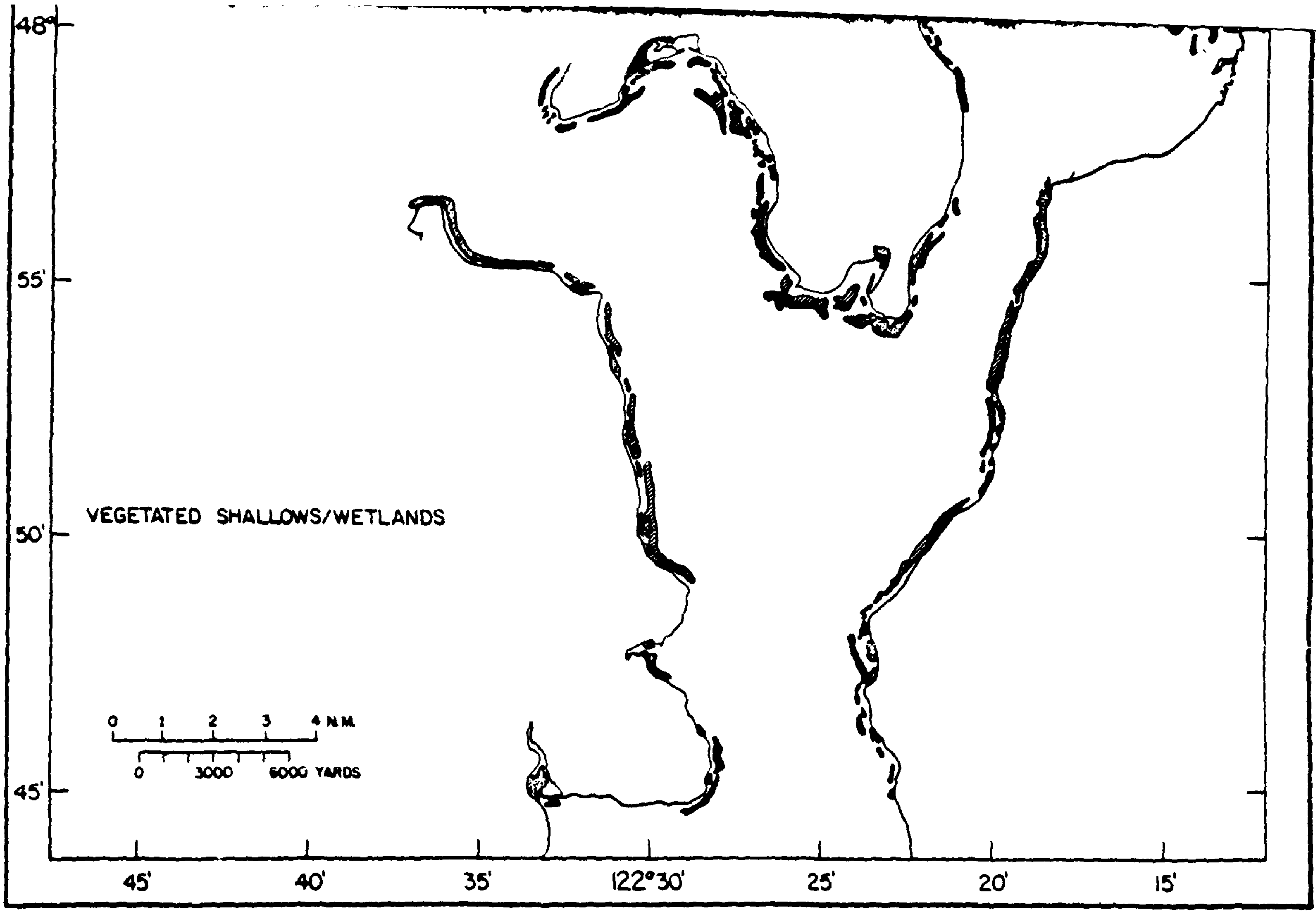
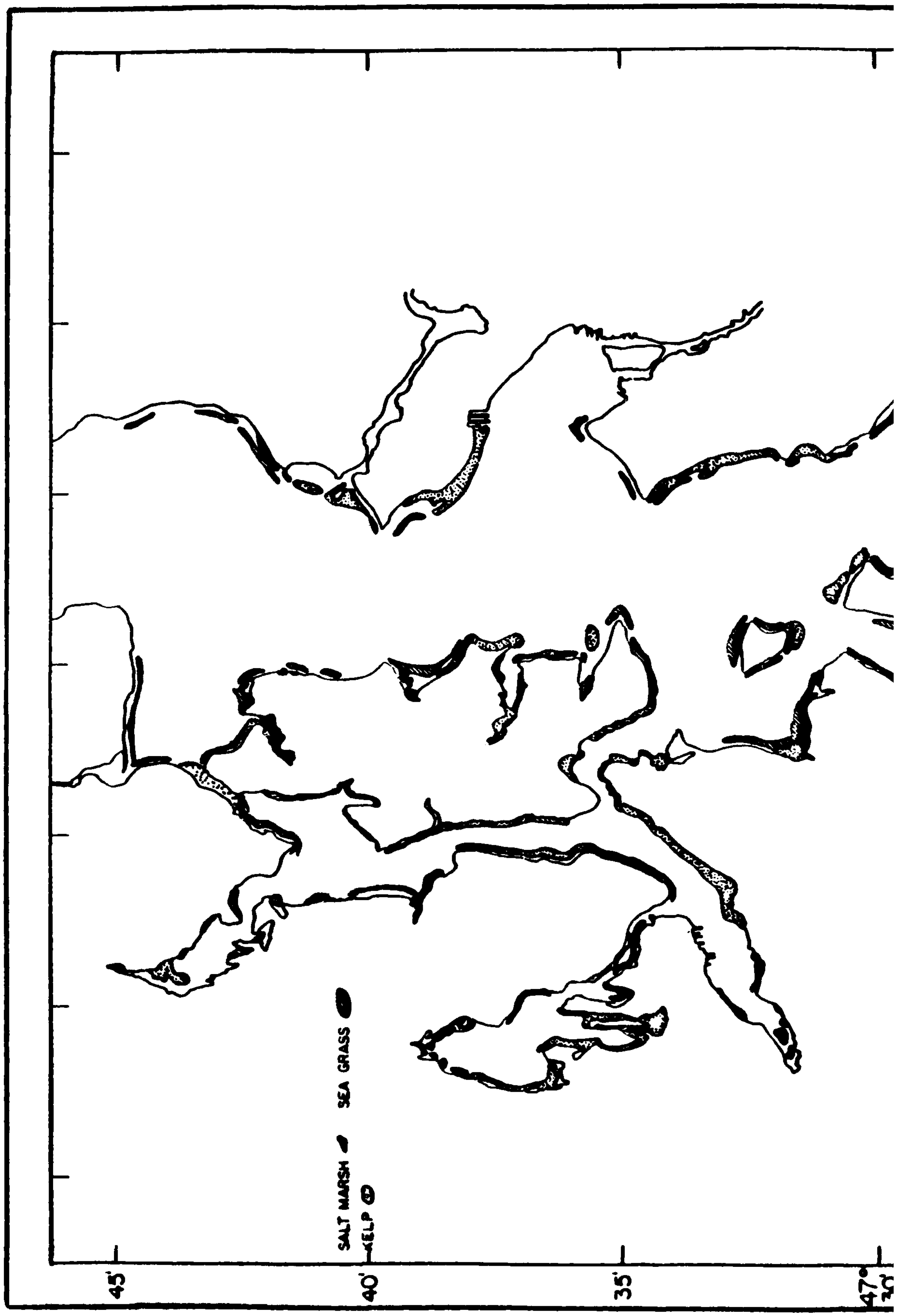

48°
55'
50'
45'
VEGETATED SHALLOWS/WETLANDS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-10A


SALT MARSH
SEA GRASS
KELP
45'
40'
35'
47° 30'

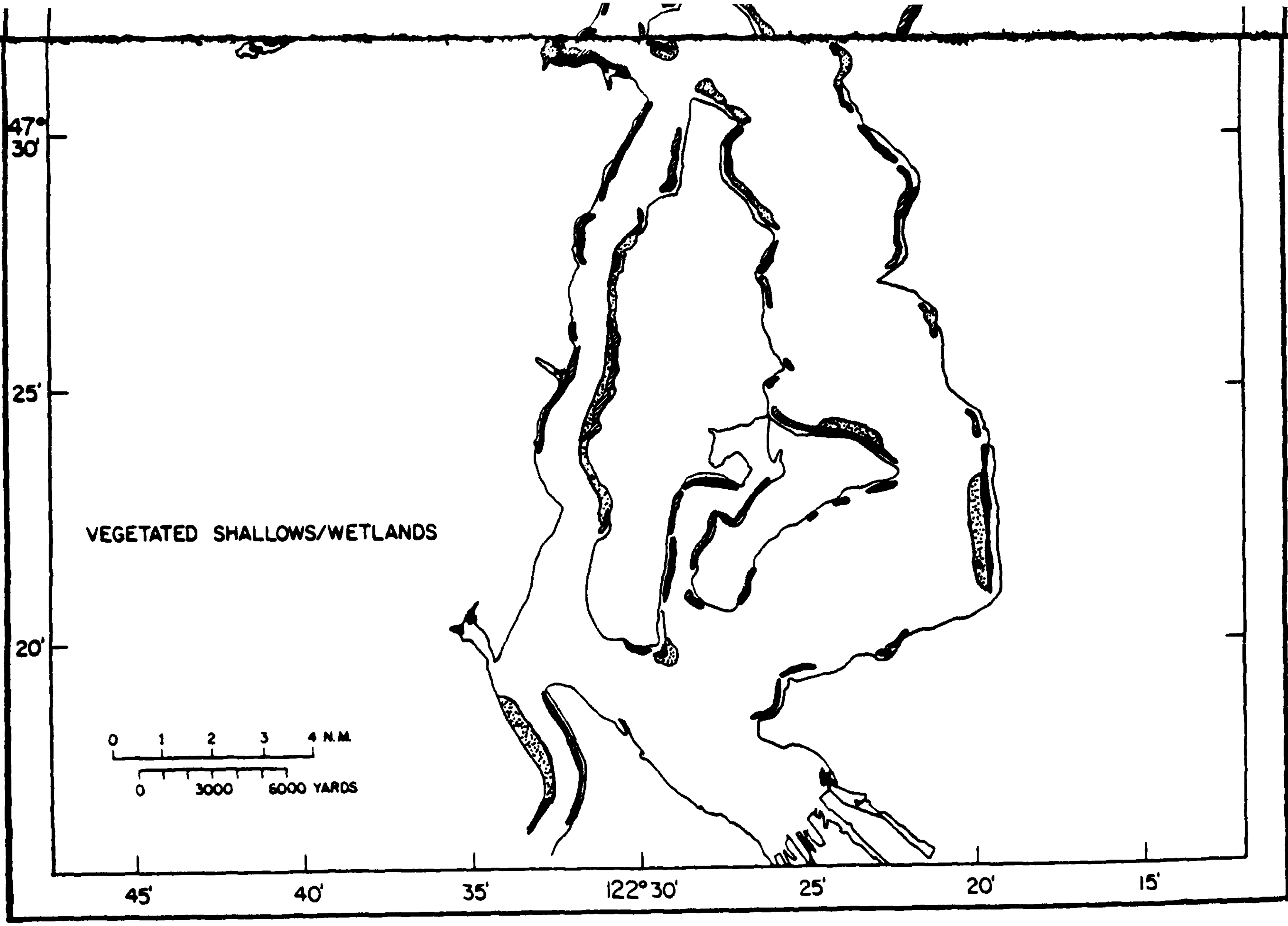
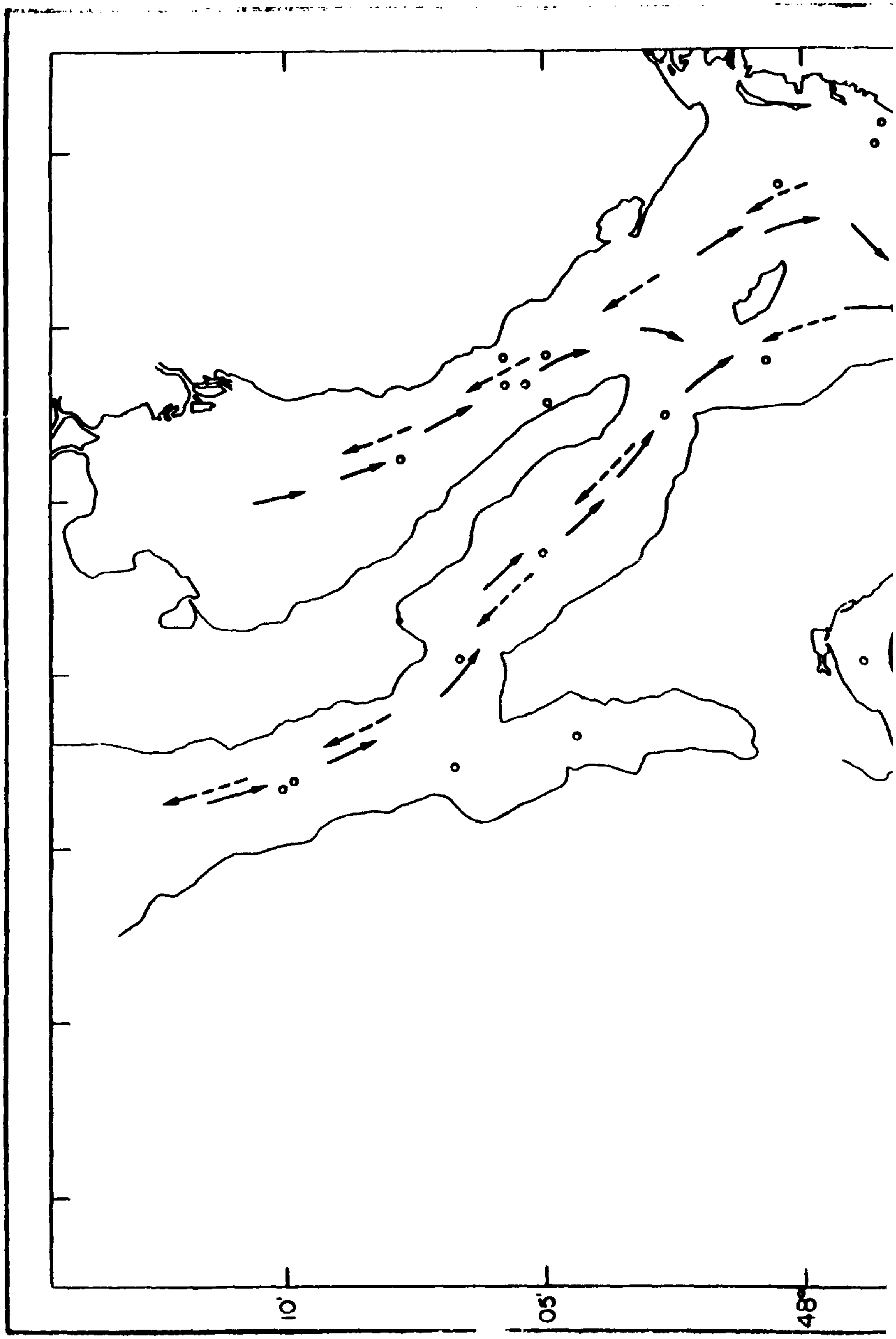

VEGETATED SHALLOWS/WETLANDS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
47° 30'
25'
20'
45'
40'
35'
122°30'
25'
20'
15'

Figure B-10B


10'
05'
48°

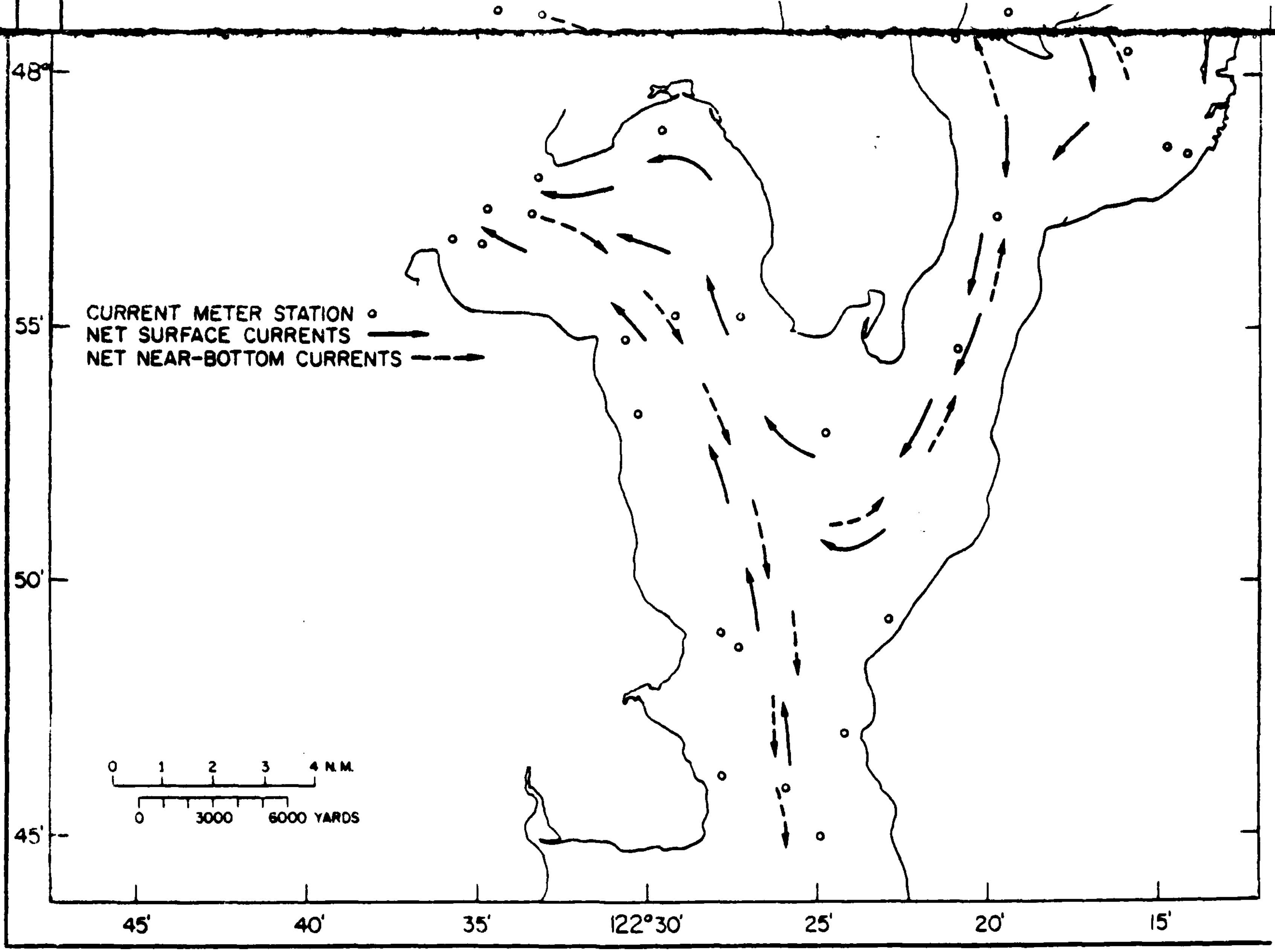
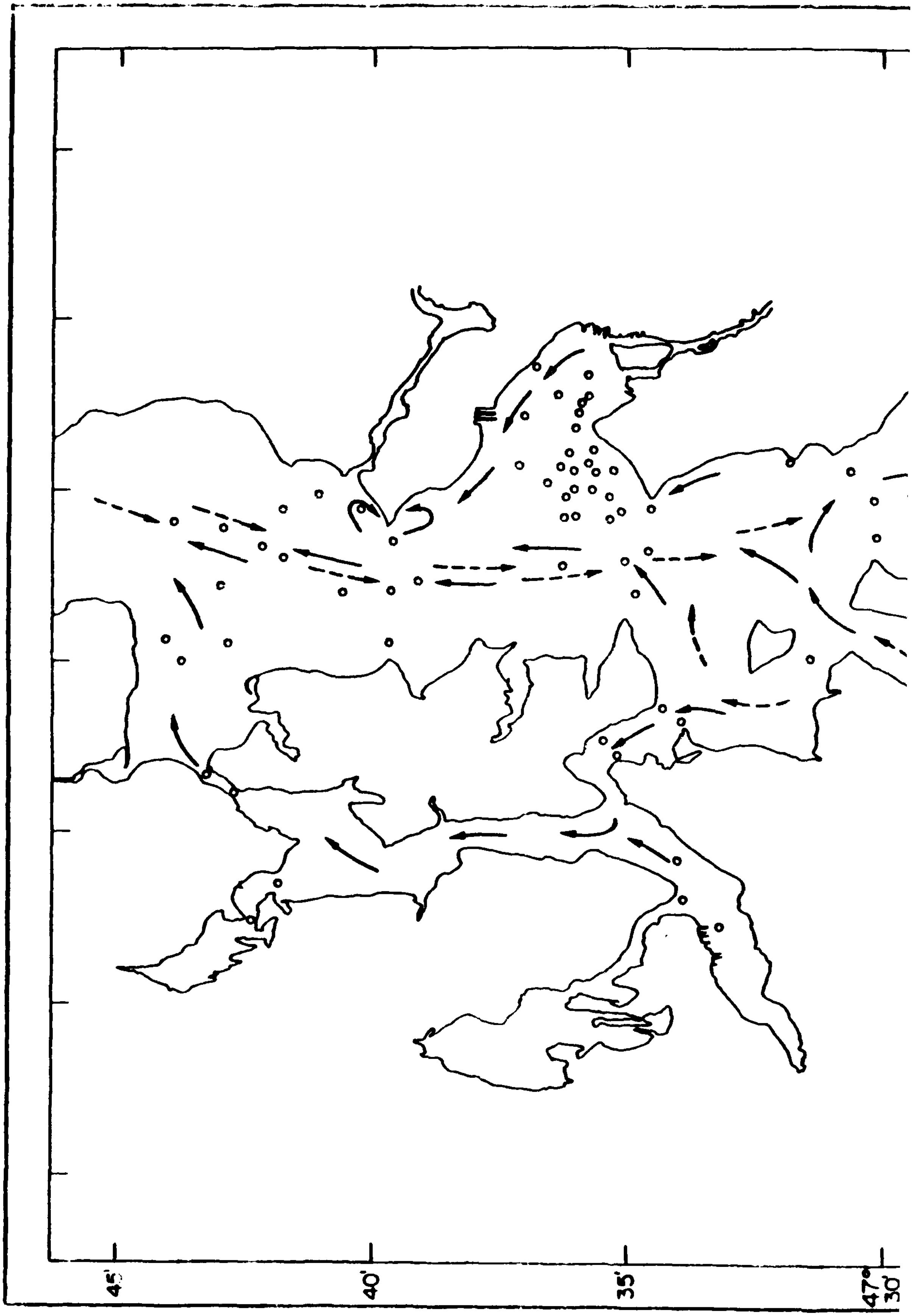
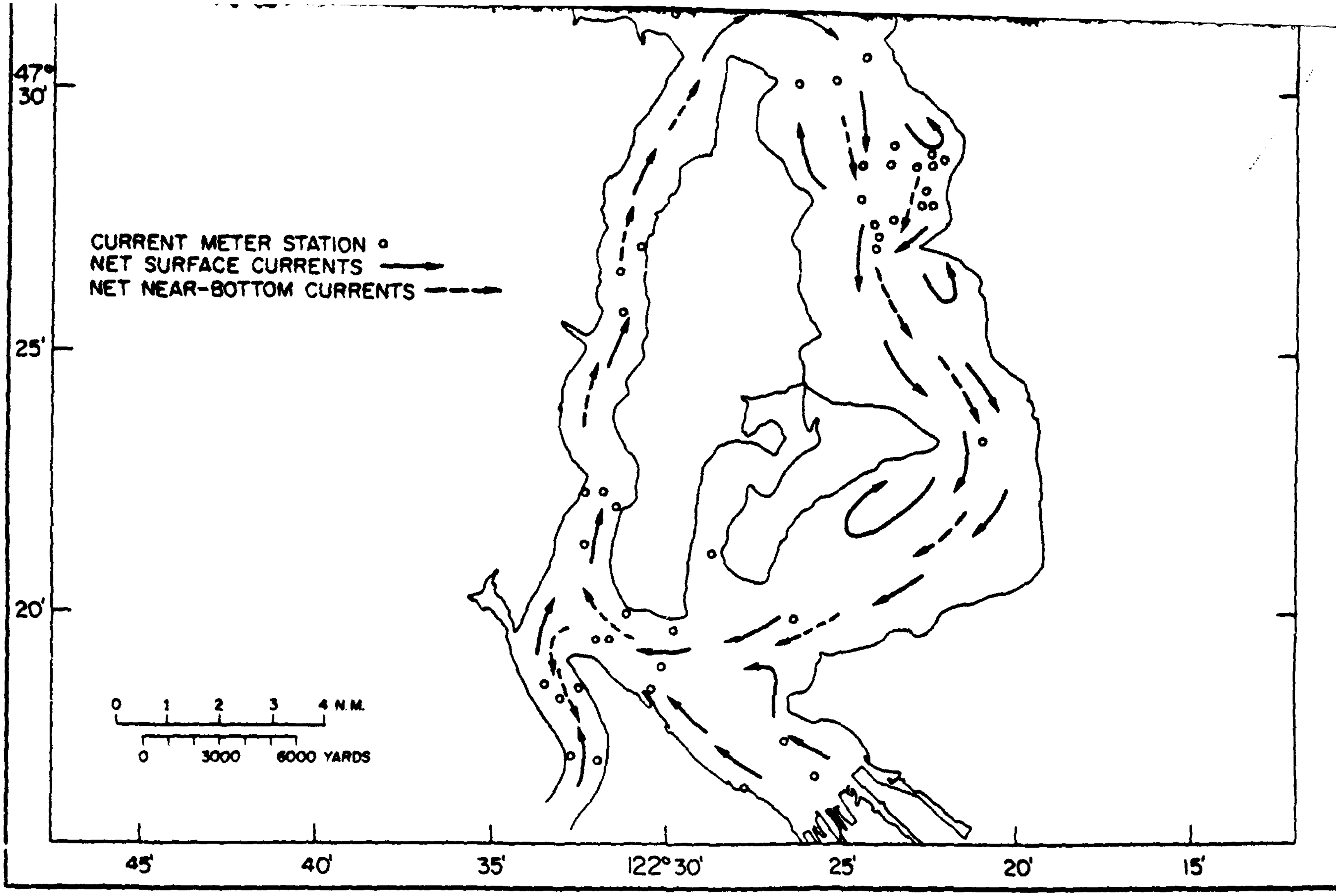

48°
55'
50'
45'
CURRENT METER STATION
NET SURFACE CURRENTS
NET NEAR-BOTTOM CURRENTS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-11A


45'
40'
35'
47° 30'



47°
30'
25'
20'
CURRENT METER STATION
NET SURFACE CURRENTS
NET NEAR-BOTTOM CURRENTS
0 1 2 3 4 N.M.
0 3000 6000 YARDS
45'
40'
35'
122°30'
25'
20'
15'

Figure B-11B

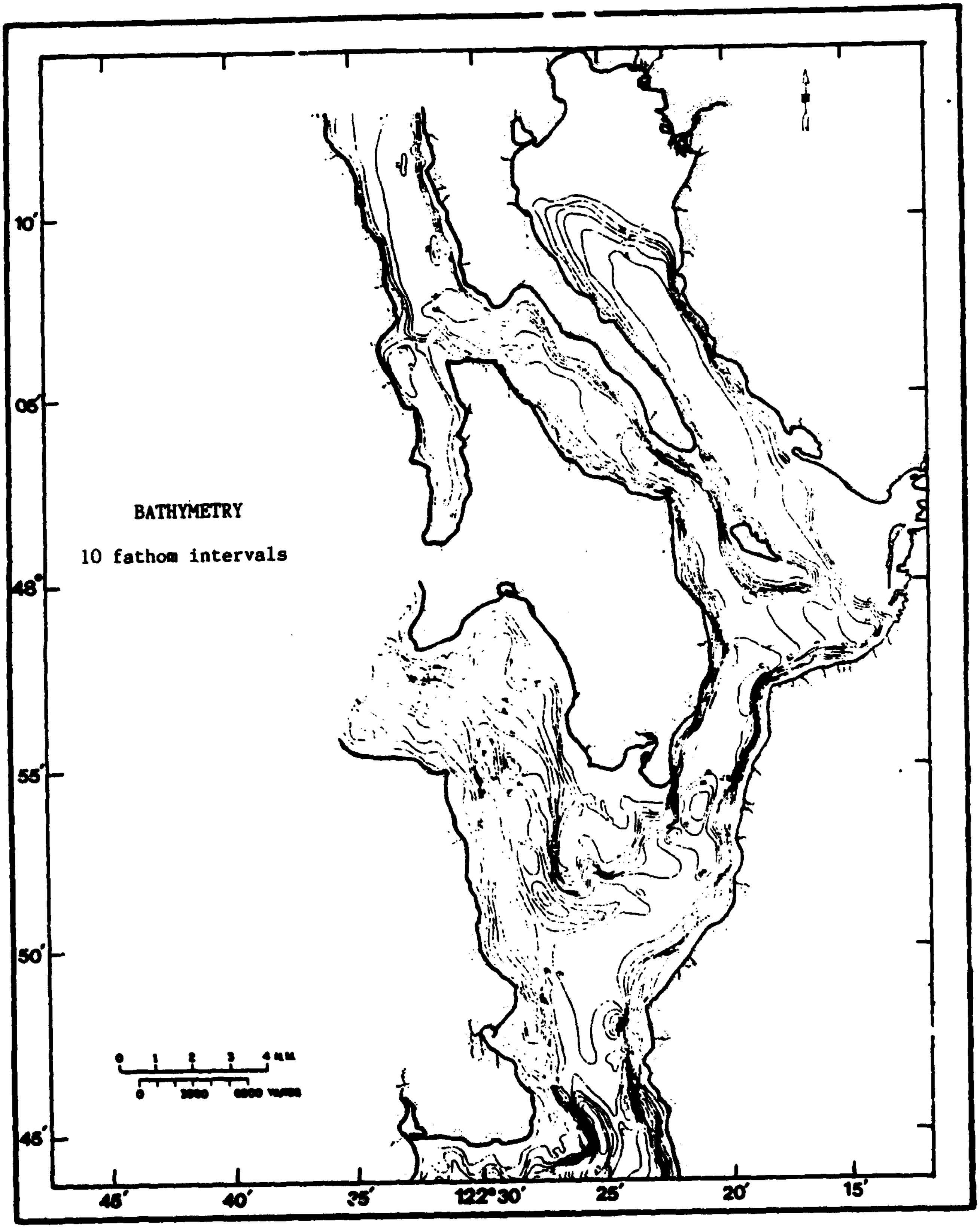
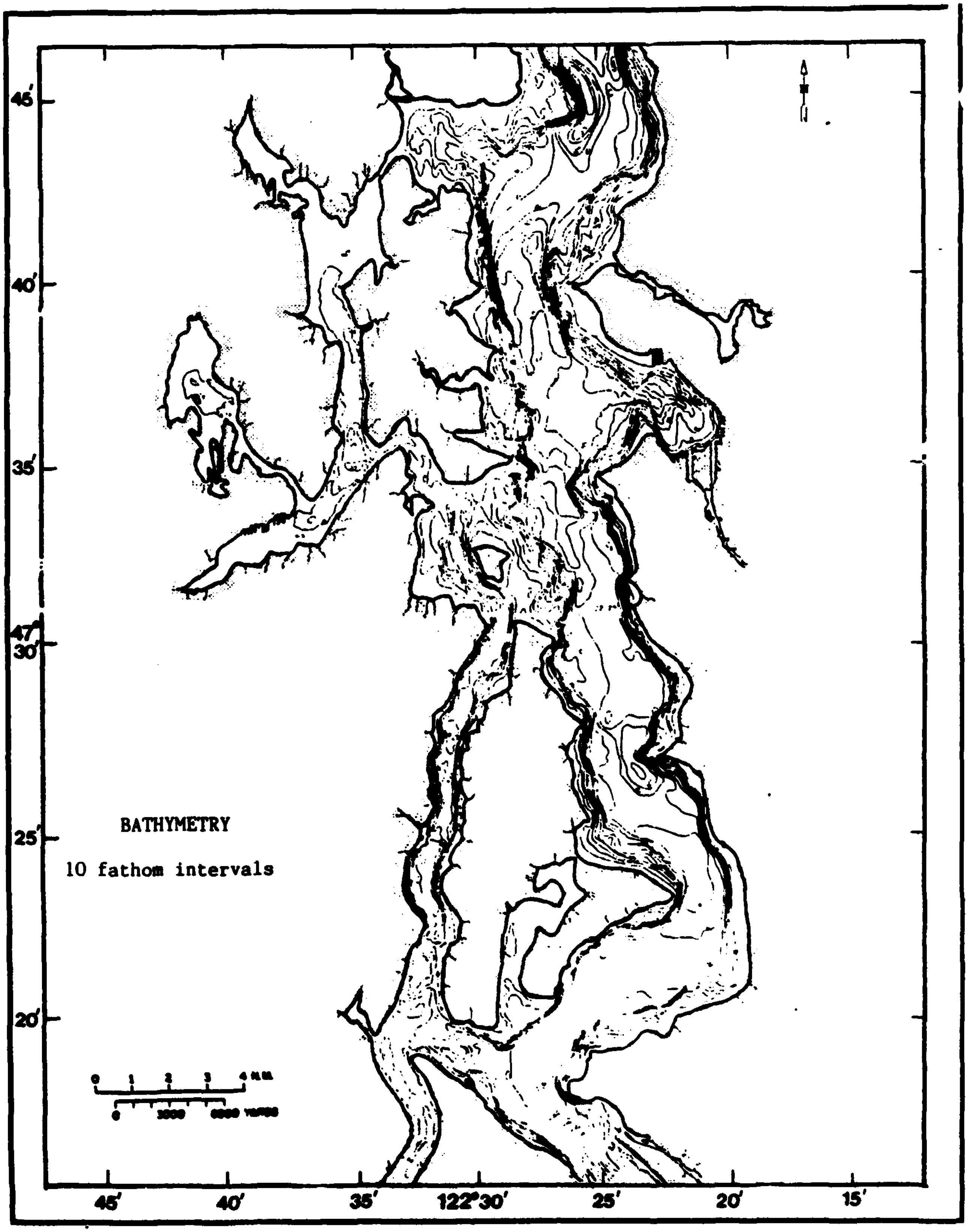
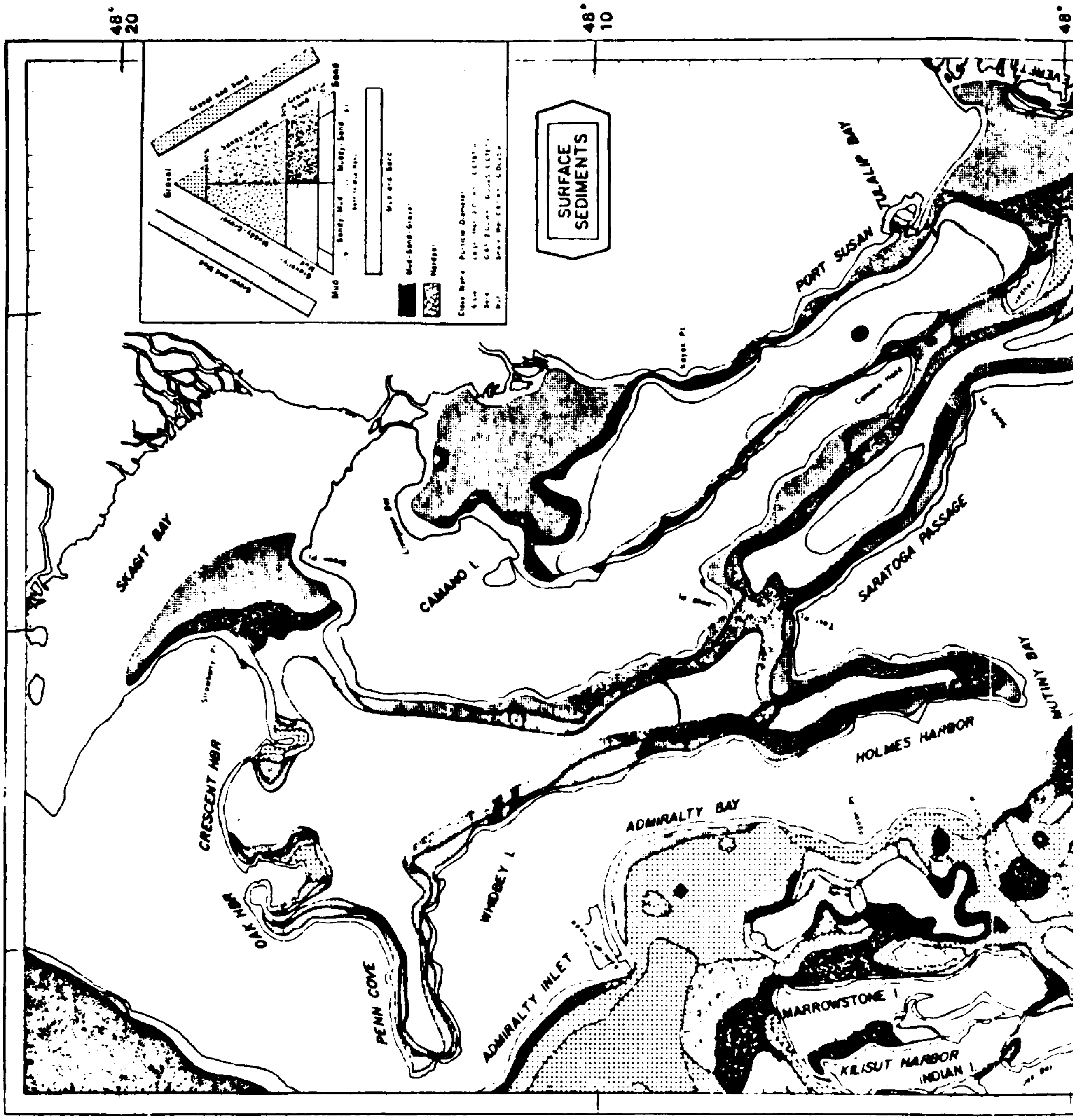

BATHYMETRY
10 fathom intervals
10'
05'
48°
55'
50'
45'
45'
40'
35'
122°30'
25'
20'
15'

Figure B-12A



45'
40'
35'
47° 30'
25'
20'
BATHYMETRY
10 fathom intervals
0 1 2 3 4
0
45'
40'
35'
122°30'
25'
20'
15'

Figure B-12B


48° 20
48° 10
48°
SURFACE SEDIMENTS
Gravel
Sand
Mud
Gravel and Sand
Mud and Sand
Mud-Sand-Gravel
Hardpan
PORT SUSAN
TULALIP BAY
SKAGIT BAY
CAMANO I.
SARATOGA PASSAGE
CRESCENT HBR
OAK HBR
PENN COVE
WHIDBEY I.
HOLMES HARBOR
MUTINY BAY
ADMIRALTY BAY
ADMIRALTY INLET
MARROWSTONE I.
KILISUT HARBOR
INDIAN I.

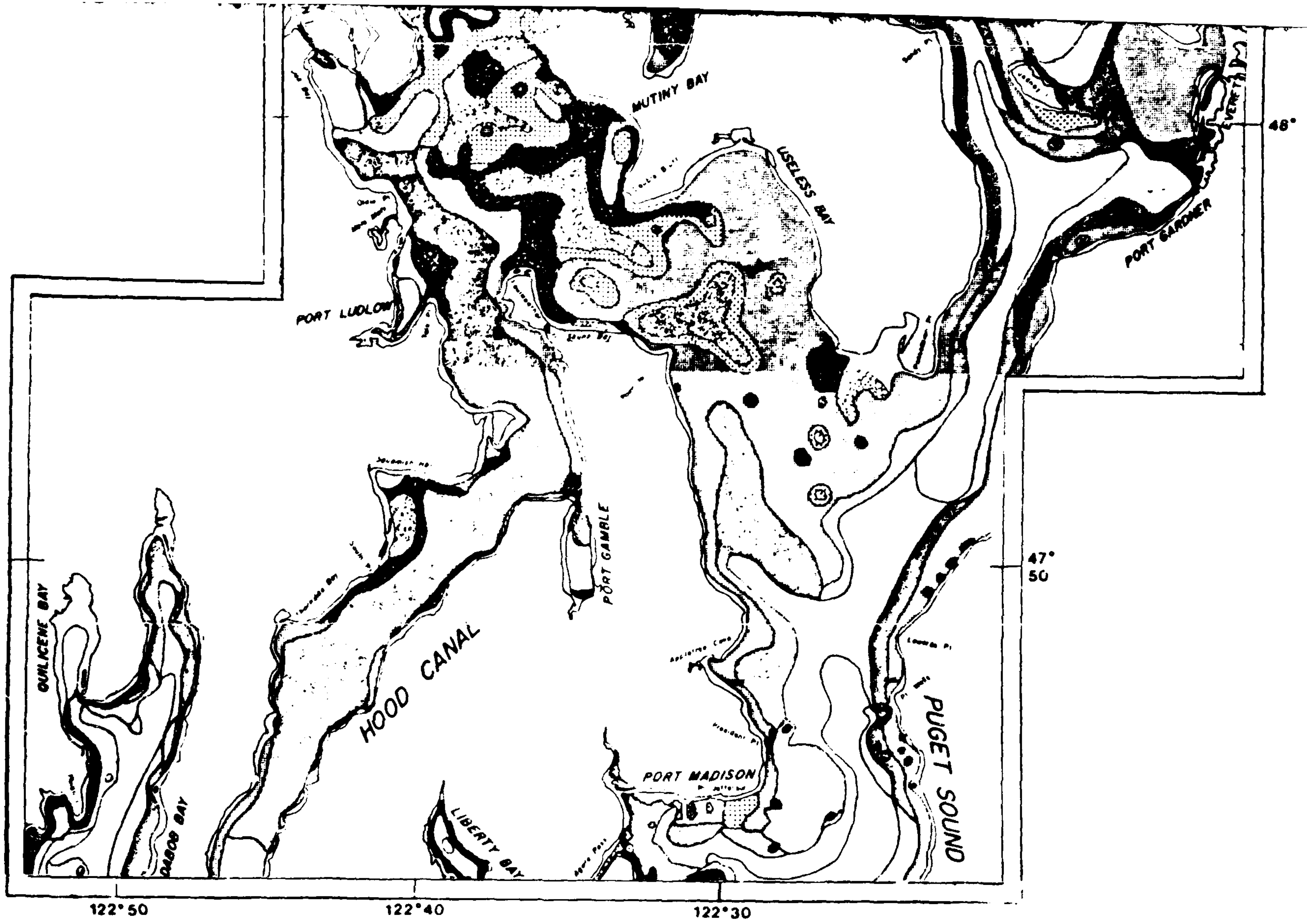
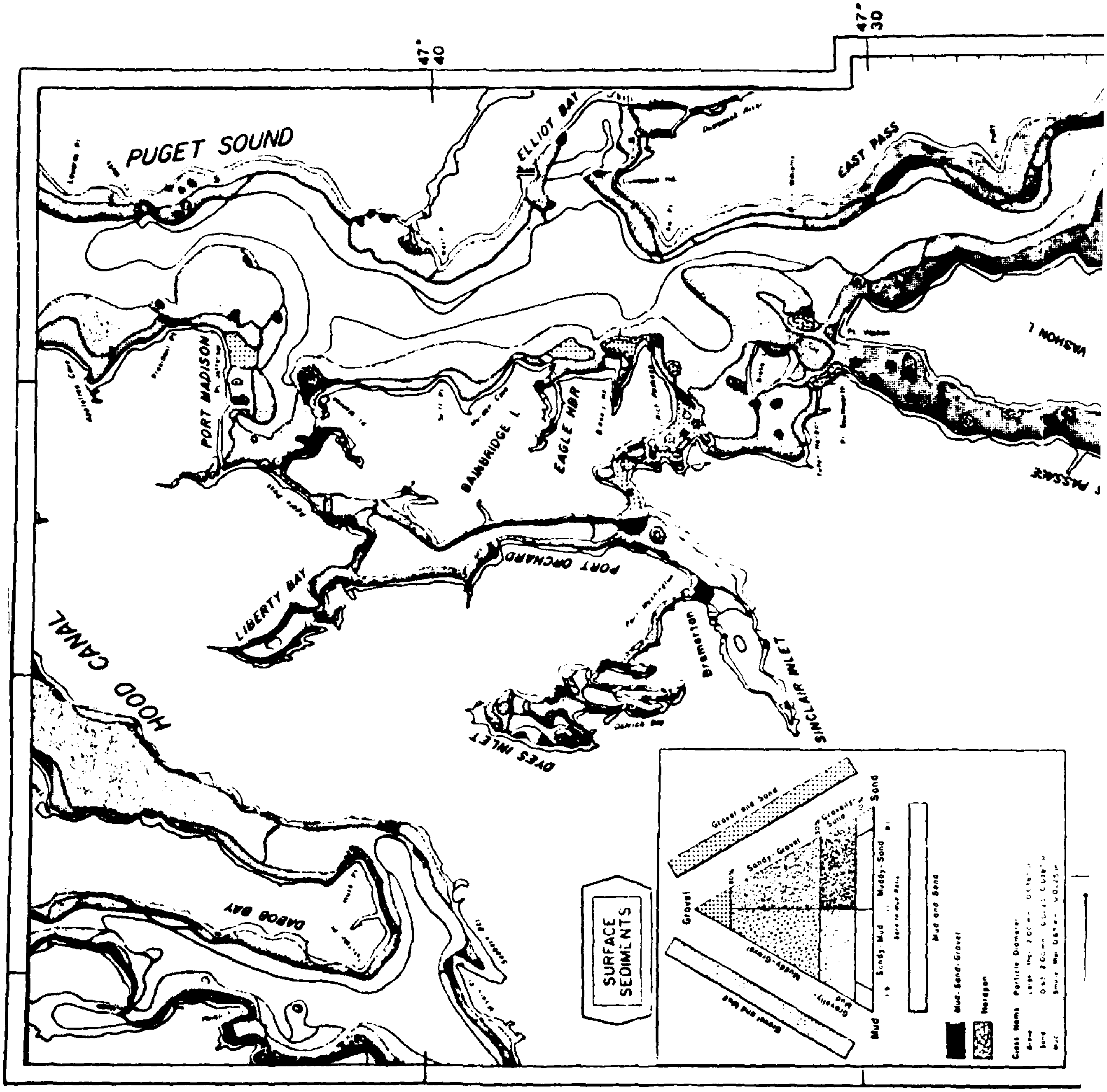

48°
MUTINY BAY
USELESS BAY
PORT GARDNER
PORT LUDLOW
PORT GAMBLE
47°
50
HOOD CANAL
PUGET SOUND
PORT MADISON
QUILCENE BAY
DABOB BAY
LIBERTY BAY
122°50
122°40
122°30

Figure B-13A


47° 40
47° 30
PUGET SOUND
ELLIOT BAY
EAST PASS
VASHON I.
PORT MADISON
BAINBRIDGE I.
EAGLE HBR
PORT ORCHARD
LIBERTY BAY
HOOD CANAL
DYES INLET
Bremerton
SINCLAIR INLET
DABOB BAY
SURFACE SEDIMENTS
Gravel and Sand
Sandy-Gravel
Gravelly Sand
Gravel
Sand
Mud
Muddy-Gravel
Muddy-Sand
Sandy Mud
Gravelly Mud
Gravel and Mud
Mud and Sand
Mud-Sand-Gravel
Hardpan


Hardpan
Class Name
Particle Diameter
COLVOS PASSAGE
VASHON I.
QUARTERMASTER HBR.
MAURY I.
POVERTY BAY
COMMENCEMENT BAY
Tacoma
THE NARROWS
CARR INLET
FOX I.
McNEIL I.
ANDERSON I.
NISQUALLY REACH
47°
20
47°
10
122°40
122°30
122°20

Figure B-13B

EXHIBIT C

SUBMERGED CULTURAL RESOURCES. ADDITIONAL INVESTIGATIONS.

1. **Submerged Historic Properties.** In addition to the work cited in Exhibit B, the PSDDA agencies undertook studies to assure compliance with Section 106 of the National Historic Preservation Act (NHPA).

2. **Legal requirements and process for considering submerged historic properties.** Section 106 of NHPA requires a responsible Federal agency to determine what properties might be affected by an undertaking. 33 CFR Part 336.1(c)(6) in particular directs the Corps to consider submerged historical properties at disposal sites. The properties should first be investigated to determine whether they are eligible for inclusion in the National Register of Historic Places. If there are eligible properties, then the effect the undertaking could have on them is determined and the documented conclusions of the responsible agency are sent to the SHPO and ACHP for their concurrence. If the project has a recognized adverse effect on an eligible property, recovery of historically important data via recording (drawings or photographs) is one of several available means to mitigate the effect. Frequently, the kind of mitigation is determined in advance through a Memorandum of Agreement (MOA) between the responsible Federal agency and the offices of the State Historic Preservation Officer (SHPO) and Advisory Council on Historic Preservation (ACHP). The steps the PSDDA agencies are following to achieve compliance with Section 106 of NHPA are summarized below.

3. **Procedures followed.**

a. **Identification and Preliminary Evaluation.** In response to comments received from the SHPO and the ACHP relative to requirements of Section 106 of the NHPA, the PSDDA agencies undertook further literature investigations beyond those described in Appendix B, and high resolution sidescan sonar reconnaissance of potential submerged historic properties in the PSDDA Phase I preferred disposal sites. As a result of these investigations, the Port Gardner and Commencement Bay sites were confirmed to lack historic shipwrecks, but the Elliott Bay site has five features that appear in the sonar records. They may represent shipwrecks. Of the five features, two are tentatively identified as the A.J. Fuller and the Multnomah. Both were built near the end of the age of sail and sunk in the early 20th century.

b. **Eligibility and Effect.** The ship presumed to be the Fuller has been determined to be eligible for inclusion on the National Register of Historic Places, and the Corps is preparing required determinations of eligibility and effect for this ship. Another

sonar feature is presumed to be the <u>Multnomah</u>, and if the tentative identification is correct, this ship would also be eligible. This feature is located near the northern edge of the disposal zone. However, the <u>Fuller</u> is at a distance from the disposal zone but within the disposal site. Through archival research, the other 3 features have not been related to any eligible vessels. Of them, one is in the disposal zone.

c. **Impact analysis** of future disposal activities suggests that properties in or very near the disposal zone could have direct impacts from falling dredged material, while those outside the disposal zone but within the site could be gradually buried by silty sands during the 40 years of anticipated site usage. The rate of burial would depend on the distance from the disposal zone. The exact locations of the features are recorded in reports generated during the sonar reconaissance; thus, an opportunity will remain for interested archaeological or historical groups to recover the structures in future should this be desirable. However, physical recovery is not a viable option at this time, based on information received in discussions with the State Historic Preservation Office and experts in underwater archaeology.

d. **Memorandum of Agreement (MOA).** The Corps has prepared an MOA which will be signed by the SHPO and the ACHP prior to the final decision to allow disposal at the Elliott Bay site. This MOA presents a plan of action for further investigations and for mitigating impacts to shipwrecks at the Elliott Bay site. It states that through archival investigations, avoidance and attempts to photodocument any historically significant vessels located in the Elliott Bay disposal site, full compliance with Section 106 will be attained.

e. **Archival investigations were** done to assure identification of shipwrecks and provide information relevant to the determinations of whether a ship is eligible for the National Register of Historic Places.

f. **Avoidance of direct impacts.** PSDDA evaluated two methods of avoidance.

(1) The <u>zone adjustment option</u> would entail a shift of the zone 375' to the south-southwest to provide a 300-350' clearance for the ship thought to be the <u>Multnomah</u>. This would not move the disposal site boundary, because the bathymetry of the site is such that the western and southern boundaries are steep enough to act as a containment for the dredged materials. The other boundaries have been determined using a margin of safety which, is still more than adequate to contain material with the new zone siting. The new center of the disposal zone would be at latitude N 47° 35.97 minutes and longitude W 122° 21.38 minutes. It would remain a circle with a radius of 900 feet.

(2) The <u>disposal restriction option</u> would condition dredger use of the northern segment of the disposal zone in order to provide similar clearance. With this option, neither zone nor site boundaries would move, but a 40° wedge-shaped segment on the north end of the zone would be closed to disposal activities so that there would be no disposal of materials near the tentatively-identified <u>Multnomah</u>.

The PSDDA agencies consulted with the SHPO, the Coast Guard, the Washington State Department of Transportation, the Port Angeles Pilots, Washington State Department of Fisheries, the city of Seattle Department of Construction and Land Use, and affected Tribes, the PSDDA agencies concluded that the zone adjustment option would slightly decrease resource conflicts in addition to avoiding the submerged cultural resources. Zone restriction would require additional navigation guidance for the dredger. Neither alternative would require more steps in the process of finalizing the Shoreline Permit. Potential Indian fishing conflicts that might occur under either option will be avoided through site management and conditions on permits which are required prior to disposal of dredged materials.

It was determined that it was not possible to avoid direct impacts for the one sonar feature located near the center of the disposal zone. It is a presently unidentifiable feature with approximate dimensions of 8 by 35 feet. Impacts were unavoidable because moving the zone farther away from its present location to clear this feature would cause serious conflicts with other resources and human uses, including shrimp resources and navigation concerns. However, this feature will be photographed as described below to identify whether it is a historically significant vessel; and if so, it will be photodocumented.

g. **Photodocumentation** will be used to identify and record vessels on the site and to mitigate for disposal effects. The SHPO and PSDDA agencies have agreed that the historically valuable information associated with the shipwrecks is their visible architectural features. The concern for gradual burial of the vessels outside the disposal zone is that these features will be obscured. Accordingly, an attempt will be made to examine all five objects in the disposal site through use of an unmanned submersible vehicle with a video camera. Should visibility permit, they will be photodocumented. Ships that are determined to be eligible for the National Register will be presented in a written report. Upon completion of the determinations of eligibility and effect, this will constitute full mitigation for any adverse effects due to disposal at the site. Should poor near-bottom visibility prevent photodocumentation, the literature research for the <u>Fuller</u> and the determinations of eligibility (and possibly effect) for the <u>Multnomah</u> will be completed without

further efforts to photodocument the vessels.

h. **Schedule for achieving compliance with Section 106.** The MOA establishes that the attempt to photodocument, the bibliographic search, and reporting will complete the requirements of Section 106. The photodocumentation cruise will preceed the filing of the Record of Decision so that the site may open for use without awaiting completion of reports (i.e., the determinations of eligibility and effect) to be completed. Actual site opening depends upon a city of Seattle shoreline permit in addition to Corps, Ecology and DNR permits.

LIST OF PREPARERS FOR EXHIBIT C

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